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Sustainable Water Management in San Miguel

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Abstract

The community of San Miguel, located in the La Mesa region of Panama, lacks a proper water system. There is an absence of documentation on the system. We created maps of the community and the water infrastructure and made recommendations for lasting improvement. We also developed and administered a survey for the community. With this information the community will be able to reach out to the local government to acquire fiscal assistance.

Acknowledgments

Without the help we have received along the way, this project would have been much more difficult to complete. Therefore, we would like to extend our thanks to those who helped make the project possible.

Foremost, we would like to thank Footprint Possibilities, specifically our sponsor, Rick Montanari, for working with us. He gave us an ample amount of support while our team was both in the field and constructing data analysis. Rick helped us define our scope and stay on schedule to ensure the completion of the project. He also provided us with tools that assisted us when we were in San Miguel.

We would also like to thank our project manager, Elsie Ducreux. Elsie contacted Footprint Possibilities to initiate the project.Without her we would not have had a chance to experience San Miguel and complete this project. She spent time with us in San Miguel and improved our communication with the community members. Additionally, she offered us advice and local knowledge to ensure the success of the project.

Next, we would like to thank our Advisors, James Chiarelli and Alex Sphar. This project would not have been possible without them donating their time and assistance to us. Professor Chiarelli has helped develop our project since our ID2050 seminar and has provided us with advice throughout the entire process. Professor Sphar has also provided us with guidance and criticism since we arrived in Panama and was particularly helpful when it came to moments of crisis where we felt lost.

Finally, we would like to extend our gratitude to James Tricker of Oxford University and Frances James of the University of Bristol for volunteering and assisting us with the field work in San Miguel. Their participation helped us reach our goal for the project and without their help we would not have completed the amount of work we did.

Executive Summary

Background

Panama City has significantly improved their water quality in recent years, and by consequence has made it safe to drink. However, proper water treatment is a frequent issue in the rural communities of Panama as they do not have access to the same resources as the citizens in the metropolitan areas. Residents of the rural communities are not receiving water that is safe to drink causing sickness among the residents. San Miguel is an example of one of these rural communities. Located in La Mesa region, roughly an hour drive east of Panama City, San Miguel lies at the bottom of the Sierra de Veraguas mountain range on the western side of the Pacora River.

The local water management committee in San Miguel is the Junta Administradora de Agua (JAAR). They try to keep the water system functioning, but currently there is no written history on the system or any documentation. Each household is supposed to pay $2.00 per month towards the water system, but there is no document of who has paid, and no water lines have been shut off for people who have not paid. The community has three filters, a grate filter at the beginning of the water system, a sand filter, and a holding tank where chlorine is added. There are four pressurized slow sand filters that have been built, but never used due to financial issues.

We spent time in San Miguel to create maps of the water system and community, as well as perform water tests and surveys. This information enabled us to assess the current situation and make recommendations for improvement. We worked with a nonprofit organization, Footprint Possibilities, as well as the JAAR to achieve this goal. With the information collected the JAAR will be able to gain funding from the local government and make improvements to the system where necessary.

Methodology

To accomplish our goal, we created three main objectives that guided our project.

1. Map the community of San Miguel, including houses, roads, and pipes using mWater surveyor.
2. Create and perform surveys to gain a better understanding of the community's access to water, and attitudes towards the water committee.
3. Perform water tests at different locations throughout the water system and at houses in order to determine the quality of water.

To create a map of the community we used an application called mWater on our cellular devices. This application allowed us to get exact GPS locations without using data. We walked the entire pipe system with a maintenance worker and marked critical points including filters, diameter changes, leaks, distribution pipes, and valves. Once we had this information, we transferred it onto a piece of software called QGIS, which allowed us to use these points to make a map. We numbered the locations and made an Excel sheet with the longitude, latitude, and a description of each point. The first question of the survey we administered was linked to the GPS location, so we were able to get the exact coordinates of the houses. Once we had the house locations, we were able to create another map on QGIS that included houses, restaurants, the school, and the local health center, which were numbered as well.

We created a spreadsheet of everyone in the community and within the spreadsheet there is a list of all of the survey questions along with the responses. This survey was designed to help us understand how this community receives and manages their water. The questions we asked were targeted to determine how the community felt about the JAAR and the functionality of the water system. We planned on performing a complete census of the community. Unfortunately, our census is not complete due to technical malfunctions and time restrictions. To set up the survey, we used the application mWater. When we met as a team, we decided to add a few more questions to the survey so we could have a deeper understanding of the community and the water system. The first survey we created was overwritten by our updated version, thus resulting in us losing all the responses we initially obtained. Further efforts to recover this information were impeded by scheduling and timing issues.

We knew there was a lack of information about the water system, but we needed to test the water to determine the severity of the situation. We used test strips to test hardness, alkalinity, pH, free chlorine, and total chlorine. We completed these tests at different locations throughout the community, once after a heavy rainstorm, and once on a day without any rain. With this information we were be able to analyze locations of poor water quality, and how well the filters were working.

Results

From our map we were able to make important observations about the water system. San Miguel relies on a gravity fed water system from the Pacora River. The system starts in the mountains before any houses to ensure the river is not polluted by humans or animals. Whenever it rains, the maintenance workers need clean out the filters. This is an issue because during the rainy season it rains almost every day. The grate filter, at the source, is rusted, which can lead to rust deposits traveling through the water system.

After the grate filter, the water enters a pipe and runs to a sand filter. Next, the water travels into a reservoir tank where chlorine is added to the water. The storage tank is too small to hold all the water during the rainy season, causing it to release the excess water. This is a problem because during the dry season the community frequently has an inadequate amount of water. Between the first filter and the storage tanks there are a significant amount of leaks that need to be repaired. The pipe flows directly down the mountain, following the road into the community. In the community, the water travels to the houses from distribution pipes attached to the main pipe. The pipes have many cracks, which can lead to more contamination in the water from having bacteria seep into the water system. Another issue is that the diameter of the pipes is too small to support the flow of water into the community. A significant portion of the pipes are above ground and installed incorrectly making them vulnerable to damage.

Once we completed and evaluated water tests, we discovered that the water is not safe enough to consume. Throughout the community, there is not enough Free Chlorine within the water, which tells us that the community is at risk of being exposed to harmful bacteria. The storage tank is not adding enough chlorine to the water to make it potable. At the beginning of the system, we found the pH was less than six, which is too acidic to drink, but after the second filter it rose to between 7.4 and 8.4. This is more acceptable as water is supposed to have a pH of between six and eight. We tested for alkalinity, which was in the acceptable threshold. We found that the water had a hardness of zero ppm, which means there are no minerals in the water. However, there are no specific health risks relating to water hardness. Further bacterial tests need to be done to determine exactly how unsafe the water is to drink.

The results of the survey stated that people were generally satisfied with the water service. We suspect that they are only satisfied with the fact that they are receiving water and not necessarily with the quality of the water. Eighty-six percent of residents surveyed stated that they were drinking tap water, and 59% of those people said they were not treating the water. Thirty percent of residents said they get sick from drinking the tap water. In addition to this 30%, ninety-one children under the age of five in 2018 have had water related illnesses. Since adults have been drinking the water for so long they have built up more of an immunity, but children are are much more susceptible to harmful bacteria in the water.

Conclusion and Recommendations

The primary concern for the JAAR is to properly repair the current damages to the pipes. These include replacing the metal grate and fixing any cracked pipes. The community should improve the current conditions of the sand filter and use the four unconnected pressurized slow sand filters as this would improve the quality of water before entering the pipes. Additionally, the pipe diameter should be increased to improve the distribution of water. Our final recommendation is for the JAAR to improve the organization of payments and have more communication with the community members. These may be difficult changes without proper funding, so it is important that the JAAR reach out to the local government to acquire fiscal assistance.

Authorship

Each member of the team participated in surveying the community, conducting water tests, and mapping the community and water infrastructure.

Anna Matsco
Anna completed research on water in Latin America, urbanization, and sand filters and was the primary writer for those sections. She also contributed to the Methodology section on surveys, and analyzed the results for the survey as well as wrote the section on surveys in Results. Anna developed the maps seen in the appendices and contributed to the recommendations and conclusion section. In addition to those mentioned above, she contributed to the editing.

Lucio Nicoletti
Lucio was responsible for completing research on water quality and writing the water quality section of the Background. He was also the primary writer for water tests in the Methodology section and the Results section of the water tests. Lucio was one of the primary authors for the final presentation slideshow and the final project poster.

Gavin Taylor
Gavin was the primary writer for the Abstract and the Executive Summary. He was responsible for the Introduction and the introduction to the Background. Additionally, he wrote the Background section about the JAAR along with contributing to the Recommendations and Conclusion. Gavin was also the other main author for the final presentation slideshow and the final project poster.

Christian Tweed
Christian was the primary editor for the paper to make it as cohesive as possible. He also researched and wrote the Background sections on community water resource management and challenges in water management. In addition to these tasks, he was responsible for writing the Methodology section of mapping the infrastructure. Finally, he was responsible for writing the Results section on the water system map and the social infrastructure map.

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1.0 Introduction

Due to the urbanization and subsequent population growth in Panama City, the demand for water has outgrown the capabilities of the current water infrastructure system. The current population of Panama is just over four million based on the United Nations estimates and is continuously growing (worldometers, n.d.). Panama are having chronic problems with water management. Water treatment and distribution systems are known to fail periodically for indeterminate amounts of time and without warning. This makes it frustrating for residents when, in the event that water is needed, access is impossible. The main issue resides in small rural communities surrounding the city. Many of these informal, recently settled, communities are surrounded by or built upon landfill, which further sullies the already questionable water supply. Consequently, the population is at risk for serious disease and infection.

An example of one area that suffers from issues connected with Panama's failing water infrastructure is San Miguel, which is a rural settlement located north east of Panama City. A major problem for San Miguel is an insufficient water supply. The Junta administradora del Agua (JAAR) is the local water committee that attempts to improve the ongoing issues. Currently, the infrastructure has fallen into disrepair and new solutions are needed moving forward. The water is not being filtered properly, and the water system was not implemented correctly. There is no documented history of the water system and no map of the infrastructure or community. Due to the lack of information it is difficult to make necessary repairs. Additionally, the community lacks the necessary funds to make lasting improvements.

Located in Panama, Footprint Possibilities is a nonprofit organization that focuses on providing rural communities with more reliable access to water. By working with the JAAR and

Footprint Possibilities our team developed a comprehensive map of the current water and social infrastructure in order to find new ways to improve the current water system. We located critical points of the infrastructure, so the community will be able to make repairs. Additionally, we collected information through surveys and water tests to determine the potential health risks and functionality of the water system. With this information the community will be able to move forward and make lasting improvements to the water system.

2.0 Background

Improved drinking water has become much more common in developed countries around the world, but this improvement is concentrated in urbanized areas. Consequently, access to clean and safe water is still an outstanding issue in large parts of rural Latin America. While urban areas have experienced an increase in access to clean water, rural communities are much less fortunate as government involvement is often absent, so communities are forced to develop solutions independent of outside help. San Miguel is a small rural community in the La Mesa region of Panama that experiences difficulty finding safe and clean water without the help of the Panamanian government. The citizens of San Miguel are encountering many issues due to the failing water infrastructure. The condition of San Miguel's water system is due to four main causes: climate, economy, infrastructure, and population growth. With the combination of a severe dry season and a low-income economy, the poorly implemented water infrastructure cannot support a growing population in the rural community. In the remainder of this section we will discuss the economy in Panama, current condition in San Miguel, possible solutions for water management, and potential challenges in successfully delivering clean water to this community.

Section 2.1: Water in Latin America

In 2015, 91% of the world was accessing water from an improved water source (WHO/UNICEF, 2014). Improved water is defined as "a source or delivery point that by nature of its construction or through active intervention is protected from outside contamination, in particular from contamination with fecal matter" according to Millennium Development Goals (MDGs) (WHO/UNICEF, 2014). Some examples of improved drinking water sources include piped water into a dwelling, tube well or borehole, and protected dug well, while unprotected sources include unprotected springs, unprotected dug wells, and surface water (WHO/UNICEF 2014). In Latin America, improved water sources are most common in urban or wealthy areas, while lower class rural areas continue to struggle. Haiti, Nicaragua, Colombia, and Peru are the most extreme examples as the percentage of people with access to clean water is 20% greater in urban communities than in rural communities (Prado, 2015).

In Panama, 98% of the urban communities have access to improved drinking water while only 89% of rural communities have access to improved drinking water. The difference in percentages of rural and urban populations is largely attributed to government involvement. In rural areas, there is often little to no government involvement leading to communities having to resort to community-based water management (Prado, 2015). If the water system fails residents will place blame on the water management in the community, instead of the physical infrastructure. Due to this it is imperative that the community puts enough effort into the success of the water management committee (Prado, 2015).

Section 2.2: Urbanization

Between the 20th and 21st centuries urbanization has been the main component in developing economies in countries all over the world. Rapid urbanization has been most prominent in Latin American countries. “Currently the urbanization level is slightly higher than in Europe and very similar than that observed in North America” (UNPD, 2001). Since 1950, the percentage of the Latin American population that lives in urban areas has increased from 41% to 75% as seen in table 2.2.1 (Cerrutti & Bertoncello, 2003). People started moving from rural areas to urban areas due to an increase in poverty in rural communities. In 1990 34% of residents in urban communities were living in poverty, while 53% of rural communities were poverty ridden (Cerrutti & Bertoncell, 2003). The high percentage of poverty in rural communities in Latin America can be attributed to the increase in civil violence and economic disadvantage (Cerrutti & Bertoncell, 2003). The most common form of income in rural areas was previously agriculture, but an increase in technology, and specialized production has been detrimental to residents who rely on agriculture as their main source of income (Cerrutti & Bertoncell, 2003).

Region*	Year				
	1925	1950	1975	2000	2025
World	20.5	29.7	37.9	47.0	58.0
More developed regions	40.1	54.9	70.0	76.0	82.3
Less developed regions	9.3	17.8	26.8	39.9	53.3
North America	53.8	63.9	73.8	77.2	83.3
Latin America	25.0	41.4	61.2	75.3	82.2
Europe	37.9	52.4	67.3	74.8	81.3
Oceania	48.5	61.6	71.8	70.2	73.3
Africa	8.0	14.7	25.2	37.9	51.8
Asia	9.5	17.4	24.7	36.7	50.6

* Regions are ordered by level urbanization in 2000.

Table 2.2.1: Urbanization Levels 1925 - 2025
Sources: Lattes, Rodriguez and Villa, 2002.

Panama City has experienced significant urban population growth in the past decade. Since 1990 the percentage of people who lived in rural areas has increased by 10% and will likely continue to increase (Cerrutti & Bertoncell, 2003). Recently, there has been an increase in the overall economy which has led to improved job opportunities. The unemployment rate has decreased, which has encouraged more people to move to urban areas. This increase in population density then requires an increase of water supply to the city (Whelan, O'Grady, Robinson and Taylor, 2016). Panama's water comes from the canal watershed, and it is able to support approximately 95% of Panama's urban population. Rural areas and suburbs of the city are also in need of water. "Article 106 of the National Constitution of Panama confirms that the State has the primary responsibility to develop the accessibility of drinking water and sanitation for the prevention of communicable diseases" ("The Rights to Water and Sanitation in National Law", n.d.).

Since Panama's urban population is continually growing, more people are moving to less expensive rural communities on the outskirts of the city as they seek stable jobs in Panama City. The growth of these communities is causing an increased water demand. Rural communities often rely on rivers as their main water source, which can often be contaminated. San Miguel is an example of this type of rural community, as they rely on the Pacora River as their main water contaminated source. Located approximately one hour from Panama City, many residents commute to the city during the week. Although the water in the city has been declared safe, rural areas such as San Miguel are struggling to supply safe water to their residents.

Section 2.3: San Miguel

San Miguel is in the La Mesa region that lies on the western side of the Rio Pacora. This region is located at the base of the mountains just east of the Panama Canal in central Panama. The climate in Panama is mostly tropical, but in the La Mesa region there is a tropical savanna climate. This means that the region has sharply distinct wet season from May to December in contrast to the dry season from January to April.

In terms of economic status, the majority of the community is lower class with some occasional middle-class residents. San Miguel has distinct areas of wealth distribution, where on the opposite side of the river towards the north end of town there is a high concentration lower class residents. Whereas the middle-class residents populate the south end of the eastern side of the river and the north end of the western side of the river. The center of town acts as a combination and there is no majority in terms of class. Overall, San Miguel includes six-hundred and thirty-six residents. Of these residents one-hundred and thirty-seven are children, seventy-six are adolescents, one-hundred and sixty-seven are women, one-hundred and seventy-three are men, and eighty-three are senior citizens.

San Miguel relies on a gravity fed water system. The water system originates at the top of the mountain at a grate filter as seen in figure 2.3.1 using the Rio Pacora as the main water source. The location of the source was chosen due to the fact that it lacks any farms or houses around it, so it cannot be polluted by human or animal waste. This is a particular problem with the Rio Pacora because when it rains the rain runs through the farms bringing cow waste into the water and contaminating it. After the source, the water then travels into the pipes and moves to a sand filter. From there the water travels to a holding tank where an unknown amount of chlorine is added to the water. The holding tank is where water is kept so if the pipes were to become damaged the community would still have a small supply of water. Proceeding from the holding tank, the water travels through pipes directly to the houses and is not filtered again unless the houses possess a private filter for the faucets. The water system is flawed as it has frequent leaks that can cause

Figure 2.3.1: Grate Filter at beginning of water source

further dirt and bacteria to enter the pipes. The current method to fix the leaks is not ideal as there have been instances of pushing a stick in a crack of the pipe as an ineffective attempt to stop the leak as seen in figure 2.3.2. Not only are leaks common, but there is a high probability that the inside of the pipes could be growing bacteria. There is also the question of whether the pipes can support a flow rate fast enough to supply the entire community with consistent water. The current water system in San Miguel has been in place for 15 years, which makes them quite overdue for inspection.

Figure 2.3.2: Leak at sand filter

Section 2.4: Junta Administradora de Agua

The Junta Administradora del Agua (JAAR), is immanent to the community and is responsible for the repair, maintenance, and upkeep of the water system. The JAAR has multiple positions which include president, treasurer, secretary and are filled respectively by the recently elected Inicencio Aranis, Maria Hernandez, and Ruth Díaz. One of the basic responsibilities of the members is to meet once a month to evaluate the water system and create plans to moving forward. Additional meetings that involve the entire San Miguel community are held twice a year.

In order to maintain the water system, the JAAR asks households to pay two dollars per month, while businesses pay three dollars. The Secretary and Treasurer are responsible for collecting and keeping track of money. Members of the community are asked to pay bi-monthly, and if they are unable to comply with this agreement, a member of the JAAR will go to their house to collect the payment. Currently, no one's water has been shut off, but the JAAR is implementing a new policy that if people do not pay by October the JAAR will deny water access to households. Not every resident has an account with the JAAR as the water system does not reach houses on the far side of the village forcing them to find their own source of water. This often results in the community members resorting to getting their water from the river, which is contaminated by houses and farms. For residents connected to the water system their funds are used to buy chlorine, repair the pipes, and to pay the maintenance workers.

Unfortunately, the JAAR doesn't have a physical record of who has paid, who has not paid, or where the funds are spent. This creates issues when the executive board meets since they have no previous records on which to base their policies, and due to a lack of a formal structure and rigor to the executive board there is no filing or note taking. Most of the basic information about the water system or the community itself is lacking such as maps of the community, records of the water system, and previous census data. Currently, the community possesses two sand filters and a holding tank. There are four additional pressurized sand filters that have been installed but are currently not in use. There is a lack of information on these pressure filters such as their model type and manuals. Originally, when these filters were installed, there was intent for them to be put in use with the power of solar panels. Unfortunately, the solar panels were stolen, thus leaving the new filters in limbo. This event ultimately led the town to continue using the inadequate and outdated filtration system. The JAAR recently reached out to an outside source in order to receive support for implementing a completely new filtration method, but the quote the JAAR was provided was a staggering twenty-five thousand US dollars. The executive board is currently thinking of methods to obtain such an astounding amount of money, but the

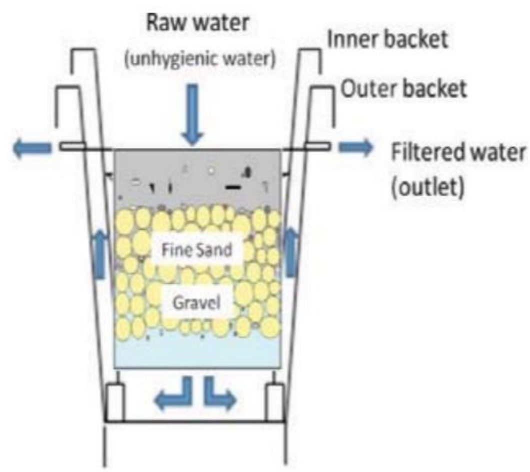
JAAR does not have a concrete timeline of when they will have the funds to be able to start using these filters.

The maintenance protocol for their current system is requesting that two local residents hike up to the source and filters and clean them using a shovel. At the grate filter, which is about a one hour hike up a sharp incline to near the top of the mountain, the workers shovel the dirt that is clogging the filter and remove any leaves that would prevent the flow of water. The next stop on is the second set of filters, this being an open roof filter with a sheet metal awning. Here there is an excess of floating debris that can contaminate the water. To clean this, one worker climbs into the tank before the water is filtered and shovels out any dirt. From there they walk to the holding tank and using the same method, climb into the tank and shovel out any excess debris. The two men make this trip, on average, twice a week. However, it is necessary for them to clear the filters every time it rains, which happens almost every day during the rainy season. Each of the maintenance workers are individually paid one-hundred dollars per month for their services.

Section 2.5: Sand Filters

In low-income rural areas potable drinking water is a major concern. Disease can be transferred via the presence of bacteria and parasites in the water, which can be deadly if not properly treated or if treatment is not accessible. Sand filters are frequently used to remedy this situation. Sand filtration devices use a perforated holding container filled with sand which is then placed in a larger container that allows water to be collected in a tank as seen in figure 2.5.1 (Kurokawa et al., 2017). In northern Vietnam, a study was done over a two-year period to determine the effect of sand filters on water (Nitzsche et al., 2015). Sand filters were preferred because they are simple, so they can be built and installed easily and they have a low operation cost. However, sand filters can clog easily, and preferential flow paths may be created, which would reduce the contact of water and the sand material, and therefore cause a lack of quality control (Nitzsche et al., 2015). The water was tested before and after it went through the sand filter and was tested three times a day (Nitzsche et al., 2015). In these specific filtration devices, fine gravel was used, and each household regulated their own filters. The results showed a significant decrease in both arsenic and bacteria, removing approximately 95% of arsenic from the unfiltered water (Nitzsche et al., 2015). Other possible filter solutions can remove up to 99% of arsenic, however, these are more expensive and require more maintenance.

Figure 2.5.1: Sand Filter



Another study was done in Western Nepal using sand filters. The community faced many diarrheal diseases, and the sand filtration devices were appealing due to their simple design and low cost. Fifteen devices were installed at nine schools and six other community locations (Kurokawa et al., 2017). Water was tested both before and after filtration using a Colilert kit. The kit aims to test for the presence of coliform bacteria and E. coli (Kurokawa et al., 2017). The results showed a visible increase in the clarity of the water, as well as a 23% decrease in bacteria and an 88% decrease of parasites (Kurokawa et al., 2017). Since there was still some presence of parasites, community members were still advised to boil water before consumption. The danger of contracting a disease from the water was no longer a serious concern in the community after using sand filters (Kurokawa et al., 2017). Both the studies in Vietnam and Nepal show that sand filters can be used in low income communities to significantly improve the quality of water.

San Miguel has access to sand filters and applying the methods used in Nepal and Vietnam could significantly improve the water quality. There is one sand filters currently being used, however, as noted above, it needs maintenance as it is very old and no longer as effective as it could be. To improve the filter, they would need to do significant amount of reconstruction on the whole water infrastructure including the piping, sand filter, and reserve tank.

Section 2.6: Water Quality

For safety and purity standards, it is common to measure the pH of water. It is measured on a scale of one to fourteen, where seven is neutral, anything below seven is acidic, and anything above seven is basic. The ideal pH for water would be seven, however, this is frequently not the case. When the pH is acidic this means there are free hydrogen ions, and when it is basic there are free hydroxyl ions. A high pH can lead to a bitter taste in water and can cause deposits in the pipes, clogging them. A low pH can be very corrosive to the pipes (pH- Water Properties, 2018). There are no specific limits to what pH is unsafe to drink, but if there is corrosion other substances, such as metals could enter the water making it unsafe, while a high pH can reduce the effect of water disinfection.

When water travels through bedrock, the bedrock dissolves in the water. Calcium and magnesium then become residue in the water and are measured respectively as hardness and alkalinity. Hardness and alkalinity should be similar in their measurements, because they both come from the same source. Interestingly, alkalinity neutralizes acid in the water (Oram, 2014). When the pH of water is too acidic from natural events such as acid rain it is beneficial to have a higher alkalinity. Still, if alkalinity is too high it can cause scale buildup in plumbing, which allows for bacterial growth, while a low alkalinity can be corrosive (Oram, 2014). Although there are no specific health risks with hardness and alkalinity, desired hardness is around 150 milligrams per Liter (mg/L) with alkalinity being similar.

Some of the challenges that occur with having an open reservoir is having small animals, branches, or leaves entering. This is a problem because they can contaminate the water source by adding bacteria and they can easily change the pH level of the water. When plant or organic matter decomposes it releases carbon dioxide into the water which combines with water to form carbonic acid. This is a weak form of acid, but a large amount of it can lower the pH of the water significantly and make it highly unsafe to drink (Oram, 2014). That is why the containers should remain sealed, so nothing can enter the water and contaminate it.

The probability of chlorine in a river with no human contact is unlikely, but chlorine is a common method to clean and treat water. In undeveloped countries where the tap water is not safe to drink adding chlorine can reduce the amount of diarrheal diseases that may be contracted from consuming the untreated water (CDC, 2010). Chlorine is added at the storage tank in San Miguel's water system, however the amount is unknown. Chlorine can be measured three different ways: free chlorine, combined chlorine, and total chlorine. Free chlorine is the concentration of chlorine for disinfection. Combined chlorine is the combination of chlorine and nitrogen in water, which is not as useful for disinfection. Total chlorine is the measurement of both free and combined chlorine (CDC, 2010). The measurement of free chlorine will show if there is enough chlorine to inactivate bacteria.

Section 2.7: Community Water Resource Management

One of the most important factors to consider in San Miguel is how the water infrastructure will be maintained, and who is to be in charge of the maintenance. An emerging solution to the problem of water management or general resource management in rural communities is the idea of a community-based management system (Dube, 2012). This solution has been heavily implemented in the last two decades in places such as Africa, and can be seen as a response to the lack of sustainable solutions for rural communities (Dube, 2012). Overall, the solution can be seen as "a participatory approach to development whereby members of the community largely determine issues to do with control, operation, management and maintenance of their water system" (Dube, 2012).

The community is encouraged to establish a water point management committee that is responsible for the tasks outlined above (Dube, 2012). The water point management committee will provide the community with a localized group of people who can continue to work with outside organizations in order to properly maintain these responsibilities. This is the optimal solution because it is extremely common for rural water systems to fail when managed by a distant supporting organization (Dube, 2012). Members of the community are also incentivized to continue to work on the situation as they develop a sense of ownership of the problems. (Dube, 2102). Because of this, the idea of a community water resource management system is not only an alternative, but a necessity. This is a more efficient and sustainable solution compared to a community that is completely dependent on an outside organization (Dube, 2012). The community-based approach performs well in less developed nations as it does not impose additional stress on an already exhausted or struggling economy (Dube, 2012). There are possible issues that need to be accounted for during development. One of the major issues of community-based water management systems is that it can be seen as a governmental abdication of responsibility. Even though it may be an abdication of responsibility, it may still be necessary in order for the community to survive (Dube, 2012).

An excellent example of the conflicting issues in this paradigm is Zimbabwe's Gwanda District. In the Gwanda District, community members continue to acquire their water from boreholes (Dube, 2012). These boreholes have fallen into extreme disrepair, where only about 60% are functional, and they provide more than 40% of the residents' main source of water (Dube, 2012). Many of the citizens walk more than half a kilometer in order to acquire water, while there are even some families that walk up to eight kilometers for water (Dube, 2012). This situation is unsustainable as a maximum distance one should walk for water is half a kilometer (Dube, 2012). The current water point user committees are dominated by men, while 85% of the women actually fetch the water from these long distances (Dube, 2012). Gender inequality is a barrier that prevents a more efficient and well adapted solution (Dube, 2012). An additional problem that demands consideration is the need for a continuing effort to maintain the committee. In the Gwanda District many of the committee members die of HIV, or move to other places, causing a shortage of prospective new members to replace them (Dube, 2012). As a consequence of this, many committees fall into disuse or fall apart entirely. This can be mended by having a policy of training new members at specified intervals. Another issue that may arise is that many of these poorer communities lack the funds to properly manage these situations on their own (Dube, 2012). However, this can be rectified by having communal side projects that generate funds for the maintenance of water systems (Dube, 2012). These ideas must be kept in mind when moving forward with a community based water management system, as these problems might prove to be more trouble than they are worth without proper planning and anticipation.

San Miguel uses the JAAR as a community-based water management committee, but they currently lack maintenance workers, as the head maintenance worker recently quit to pursue a better paying job. The management in the community will need to be improved and expanded to ensure the water system does not fail. For example, the previous president of the JAAR, failed to give the current president, Inicencio Aranis, any documents relating to the water system. When we arrived at San Miguel Inicencio Aranis did not provide the team with any information because he did not have this information, so we had to obtain it for him.

Section 2.8: Challenges in Water Management

Sustainable water management is important but will be worth nothing if it cannot endure a growing and changing community. A study was done in Arraijan, Panama sampling water from five different zones each with different challenges. The biggest problem in this community was intermittent water supply which is when “water utility is unable to continuously maintain positive pressure in the entire piped drinking water distribution network” (Erickson, Smith, Goodridge, & Nelson, 2017). Intermittent supply was caused by insufficient resources, weak infrastructure, unplanned expansion and water loss. Another challenge this community faced was damage to pipes, which caused contaminated ground water and microbial regrowth (Erickson, Smith, Goodridge, & Nelson, 2017). Due to the expanding community in Arraijan, they did not have enough water to supply the entire community, and their system of water distribution was outdated making it difficult to consistently receive water. In San Miguel, the residents face a similar difficulty as houses furthest from the water source lack access to the water system. It will be important to keep in mind the negative effects a poor water management system will have on a growing community.

Another interesting example is China and its relationship with its water usage. In recent years, China has faced water shortages due to high population density, which is estimated to grow until 2030. The main causes are inefficient use, waste water that contaminates freshwater, pollution, and socio-economic development. Wastewater discharge pollutes freshwater and eliminates a sanitary source of water (Jiang, 2015). Similar to Panama, China has experienced rapid urbanization, which requires water supply to keep up with the growing population, causing a growing demand for agriculture in order to achieve food security (Jiang, 2015). The main interest of the government is economic growth, so although the government does have some involvement in the water security it is not a main priority and only 1% of rural communities have wastewater treatment (Jiang, 2015). By looking at the challenges China has faced with water scarcity we can compare similarities to Panama and try to better manage the current water supply.

Climate change has caused changes in precipitation patterns. In China, the north is experiencing higher temperatures than the south causing a decrease in annual precipitation in the north and an increase in rainfall in the summer and winter for the south (Jiang, 2015). Climate change is forecast to cause longer and more frequent droughts in addition to other severe weather such as tsunamis. This will lead to major issues for residents and will be extremely dangerous for agriculture (Jiang, 2015). In addition to droughts, there will be higher sea-levels, endangering coastal agriculture, and higher water temperatures causing lower water quality (Iglesias & Garrote, 2015). It will be important to understand how the changing precipitation patterns relates to climate change in San Miguel, as they already struggle the most to maintain water during the dry season when there is less rainfall. Panama faces many challenges similar to rural China such as a growing population. By studying similar communities, we are able to better understand the situation to determine the most effective solutions.

3.0 Methodology

The goal of this project was to gain a better understanding of San Miguel's water system through mapping and surveys in order to develop feasible recommendations for improved water quality. Overall, the community had almost no information on the residents and water system beyond personal memory of the JAAR members and maintenance workers, leaving an important demand to create material records of both the water infrastructure system and water related information regarding the members of the community. Correspondingly, the main two aspects of our project were the social surveys and the physical infrastructure of the water system. We used both qualitative and quantitative research methods for both the social aspect and the physical aspects of the water infrastructure. The following is a list of objectives that drove our project toward achieving our goal.

1. Map the community of San Miguel, including houses, roads, and pipes using mWater surveyor.
2. Create and perform surveys to gain a better understanding of the community's access to water, and attitudes towards the water committee.
3. Perform water tests at different locations throughout the water system and at houses in order to determine the quality of water.

Section 3.1: Mapping the Infrastructure

One of the main focuses of our project was mapping the water delivery (piping) to determine the critical points. The critical points we focused on were cracks, changes in diameter, joints, filtration points, valves, and distribution points. Mapping these locations will allow the community to establish points of concern and have the ability to better maintain the pipes. As we traveled throughout the San Miguel community, we used mWater as a field application to record these critical points. mWater Surveyor is an application designed for water mapping projects. Overall, it has many features designed for water-related data collection such as surveys, mapping, GPS location, and group functionality. The main imperative behind this effort to map the water infrastructure was that the community lacked its own map of the piping system, which was due to its unplanned construction fifteen years prior. In spite of the lack of a map of the water infrastructure system, the JAAR has maintenance workers that know the entire water system. However, upon our arrival, the most recent maintenance worker had left the position for a more lucrative job opportunity.

In order to provide the community with a map of the water infrastructure system, we followed the entire piping system in the community. We started with a hike into the mountains and through the jungle to find the water source, and then we followed the pipe down the side of the mountain to the sand filter and the reserve tank. We then followed the pipe to the main road looking for any critical points or locations where the pipe came above ground or went underground. We logged these crucial points on mWater, which showed the latitude, longitude and altitude. This process continued and brought us through the center of the community and through San Miguel to the far side of town towards San Martin. Whenever the pipe was above ground or we saw anything significant, we logged it on mWater which used our GPS coordinates to acquire the location of the points.

Later, we analyzed these points and learned that we did not have enough data to make a complete map of the piping system. This was primarily due to the fact that the majority of the piping system is buried underground. The president of the water committee, Inicencio Aranis, arranged for a meeting with one of the previous maintenance workers, Chiri. He guided us throughout the town showing us exactly were the pipes turn, where the distribution lines were, how many houses they fed, and the diameter changes. We printed out maps with the points we previously logged on mWater, so while we went through the town we were able to draw the pipelines with pen. This proved to be extremely helpful because it made mapping the pipes incredibly simple and filled in many blanks where we lacked information. Following this effort, we proceeded to use the GPS data from mWater and the hard copy maps to create the final product in QGIS, an open source mapping software. QGIS is a free software that allows the user to add points based on GPS coordinates, label, and connect them to show the complete water infrastructure as seen in appendix B. The original plan was to use mWater to complete the digital map, however mWater surveyor is a new application, and currently does not have the capabilities necessary for a final product. mWater is an excellent application to use because it does not require any internet service. We created a footprint possibilities group in mWater, that includes an access code, so anyone can update the information that we have entered. If any leaks are repaired, or any new critical points are found, these locations can be removed or edited so the JAAR will have updated information.

We transferred all the points into QGIS using different layers for each type of critical point. The first component of the map was the spring, where the system started, followed by the filter and storage tank. Then we plotted the leaks, and distribution pipe locations. We made three different layers, using different colors to show the different diameters of the pipes, as well as a layer to show the exact location the pipe changed diameter. Once this information was in the system we could connect the points to make the map as exact as possible. Each point is attached to a number, which was put into an excel sheet. The excel sheet has the longitude, latitude and description of the point as a guide to the user shown in appendix L. The JAAR will now know the location of leaks and damage, so they can isolate and repair them. We were able to locate the major distribution pipes, however there are more that only feed one house and were not located. Additionally, we only saw two valves, although there are most likely more in private properties that could be added to the infrastructure map in the future.

Section 3.2: Mapping the Social Infrastructure

The social infrastructure was our next concern. The only map the community possessed was located on a sign outside of the school and consisted of the main road and small black squares to represent houses. This map was faded due to the climate, making it very difficult to read. Having a map of the houses will allow the community to isolate places where there are issues with the water, or locate the houses where people are not paying the JAAR.

One of the beneficial aspects of mWater was that the application captured the GPS location of the user when filling out a survey, allowing us to get the coordinates of the houses for each survey that was completed as seen in appendix J. From this feature, we were able to create a rough map of the houses in San Miguel. However, the map remains a work in progress due to the fact that we were not able to complete the census and approximately thirty-six houses eluded our efforts. We made sure to include the school, the restaurants, and the local health center. Once we obtained the map-related information for the households we were able to almost complete a proper map of San Miguel. The final piece we were missing was a map of the road system throughout San Miguel. In order to achieve this, we walked along the paths throughout the community and recorded points on mWater to create a connect-the-dots style simulacra of the road system. The method we used to map the road system could not account for small imperceptible curves along the road, and so is a slightly distorted but functional copy of the road system.

Afterwards, we needed to find a way to transfer the data from mWater onto QGIS as mWater was not adequate to provide a final product. We started by transferring the locations of the roads. Although not perfect, once we entered points into QGIS we had a satellite image that allowed us to see more of the roads and paths and add additional points, so the path layer was as accurate as possible. House locations were then added. The houses in San Miguel are not numbered, so we created a numbering system. Our original idea was to split the community into quarters and label the houses by N, E, S, and W, for north, east, south, and west, followed by a number starting at 001. However, on QGIS we could not label using letters. We decided to still split the community into the four directions, but labeled the houses in 100's using a different 100 for each quarter. We decided that houses in the 100's would be north, 200's would be east, 300's would be south, and 400's would be west, to follow the compass. This is shown in our final community map as seen in appendix F. Since there are approximately 200 houses in San Miguel, there was no concern that the numbers would run into each other. As stated previously the census is not complete, so in the map we skipped some numbers in areas we know are not finished allowing houses to be added later. The restaurants, bars, and stores are numbered as well, however the school and health center are not because there is only one of each.

Section 3.3: Surveys

Our next objective was to analyze how the community members use their water, and if they have access to the town's water supply. After discussing the matter with our sponsor, we reached a conclusion that our best option to obtain this information would be through a census. The main goals of the survey were to determine how the residents acquired their water, what they use tap water for, if they have experienced any illnesses from drinking the water, and their feelings towards the current water management system. This information can then be used to petition for additional funding to make lasting changes to the water system. We used the capability of mWater to take surveys to attempt to achieve this census. Once we determined our questions, we translated them into Spanish. Then, with the assistance of our project manager, Elsie Ducreux, and a bilingual Panamanian resident, we proofread them to ensure that the translation was as accurate as possible. The questions were set up as either yes-no questions, multiple choice questions, or questions where the response would be a number. We simplified the questions as much as possible, so we could understand responses, as we do not speak Spanish and the residents of San Miguel do not speak English.

On the first day spent administering the surveys, we had three JAAR members helping us, however they only spoke Spanish. We also had two volunteers from the United Kingdom, but they did not speak Spanish. We split into three groups of two to complete the survey, each with one JAAR member. mWater has the capability to record the location the questions were answered, which was very helpful when completing these surveys. The first question on the survey was used to determine if anyone was home at the time we were completing surveys as seen in appendix A. If no one was home this allowed us to answer that the survey was not complete, so we had the location of the house and could go back at a later date to receive a response. We were also informed that about twenty houses in San Miguel were without water, so having the location of the question allowed us to see where exactly these houses were located, and if they were concentrated in one area. When we walked to each house a JAAR member would introduce us and we would proceed to ask the questions. We went to houses with JAAR members four different times, however after the first trip we only had one member with us, making the process much slower. Due to the language barrier and time limitation the last trip we made was without a JAAR member, which was more difficult, but since we knew the questions by this time, we were able to get the information we needed.

We did not complete the census as planned, so we had to do a sample analysis with the information we obtained. To do this we downloaded the survey results on to an excel sheet and made charts about the most relevant information. The goal is that others will be able to complete the survey with the mWater access code and in the meantime the JAAR can use the information we collected to get funding for the water system.

Section 3.4: Water Quality Tests

To assess how well the water system and filters were working we performed water quality tests. Testing the water quality tells us how well the current system is functioning. The chemical tests we completed were pH, free chlorine, total chlorine, hardness and alkalinity. Testing water quality helped us move forward in our analysis and determine what changes need to be made and where the water quality is the poorest. If there is a significant pollutant present in the water, we can target this and improve our concept for a sustainable water system.

We tested the water at several different test sites along the main pipe and in the community. The material we used to test the water were pool strips found at a local hardware store as seen in figure 3.4.1. The first test location was at the

Figure 3.4.1: Water Test Strip

first filter where the source is located. At this filter, we tested the source, where the raw water is located. Then we walked down to the next filter and tested the water before it was filtered again. Walking down a little further, we reached our third test site which is the holding tank where chlorine is added to the water, and we tested both before and after the chlorine was added. This is the final filter before the water enters the pipes and travels to the community. We wanted to assess the degree to which the filters improved the quality of water, so we also chose significant locations in the community. We tested house we were staying at, which would act as a baseline for the quality of water in the houses. The final stop was a restaurant, to see the quality of water that was being used to prepare food. We completed these tests twice to see if the results varied or if they were consistent. The second time the water tests were done was after a rain storm, so we could see if the rain affected the quality of water at any point in the system by diluting the chlorine or adding any other substances that could potentially be unsafe.

4.0 Results

In the previous chapter, we summarized and discussed our methods for accomplishing the goals we had set for ourselves. These goals were, once again, to create a map of the households, create a map of the water infrastructure, create a census of the San Miguel population, and test the water at varying locations. To cover our progress briefly, we were able to create rough but functional products of all our goals, but we were not able to finish the census in totality. Despite these incompletes within our project we were satisfied with our final products, along with our project manager, Elsie. The final products will allow the community to reach out to other groups with the hopes of securing additional assistance. In our opinion, this effort proved to be successful as it lays a foundation for the community moving forward. One of the important things to remember with a project such as this is that it is never quite done, and there is always more data to consider.

Section 4.1: Water Infrastructure Mapping Results:

From an engineering standpoint, we found many flaws with the water system. The source is located a good distance up one of the nearest mountains, and there is no direct path that leads to it which means that the hike itself is physically taxing. The path that leads to the source and the reservoir tanks cuts through cow pastures, woods, and local farmland. As noted before, there is a metal grate that acts as a rough filter for the water as it enters the pipes. This presents an issue because after every heavy rainstorm, the maintenance workers have to hike into the mountains and clean the metal grate by scraping the leaves off of the metal and removing any excess sand or debris that reduces the flow of water. This takes a great deal of time and energy especially during the rainy season since it rains almost every day. The metal filter is rusting, which is undesirable because the rust can seep into the water system and contaminate the water. The piping system is made up of PVC. The tubing itself is cheaper than metal but can break easier and often does. This is a major problem especially if the pipe is not installed properly. While tracing the pipe we saw an excess of piping above ground, which is a prime example of not installing the piping system properly. This can cause a lot of future problems because if the pipe is above ground, there is a higher chance of it getting damaged. Another problem we saw was that when the pipes crossed the road they were attached to trees and hanging above the ground without a proper suspension system. This is a shockingly poor design because that pipe can easily fall if struck by something.

There are numerous cracks and leaks in the plastic pipe. These flaws should immediately be addressed because the cracks cause a drop in the water pressure inside the pipe which decreases the rate of flow. Additionally, the cracks expose the water to outside contaminants, which puts the residents who drink it at risk. All it takes is dirt or waste to land near the crack and then seep into the piping system before the whole system becomes contaminated.

The design of the filters and tanks is also problematic. The filter is made up of sand and relies on gravity to filter the water through the sand, which only works with the appropriate grade of sand and has to be properly managed. The sand filter removes general debris and neutralize the pH (as evident from our water tests as discussed in section 4.4), but the sand is not properly maintained. One of the main issues is that it allows bacteria and finer debris to pass through. Due to these imperfections in the current implementation of the sand filter, the water is not completely sanitary and still needs to be privately filtered before consumption. Another problem is the reserve tank: it is not big enough to supply the whole community. In order to have an operational storage tank the volume should be large enough to supply the entire water system, while the supply source is not operational (Water System Design Manual, 2001). During the rainy season the community receives such a substantial amount of water that the tank's overflow valve is constantly being put to use. This is an issue because during the dry season there is frequently not enough water to supply the community. In addition to this, the reservoir is not sealed, indicating that it is open to debris, dirt, or small animals contaminating the stored water source. The concrete within the containers can also foster algae that can contaminate the water.

One particular flaw we noticed was that the pipes passed by four pressurized sand filters that were not connected to the water infrastructure system. These pressurized sand filters, once filled with manufactured sand, will foster flora that will consume more harmful bacteria such as E. coli. They are of a fine enough grade to prevent contaminants from remaining in the water. However, the pipes are not connected due to the fact that at one point the community had solar panels to power the filters as there was no power lines running through the area, but the panels were stolen before the filters could be activated. Now, the community is no longer in need of solar panels as the power system runs past the filters, but it will be costly for the community to connect the filters with the local power system.

Section 4.2: Social Infrastructure Mapping Results:

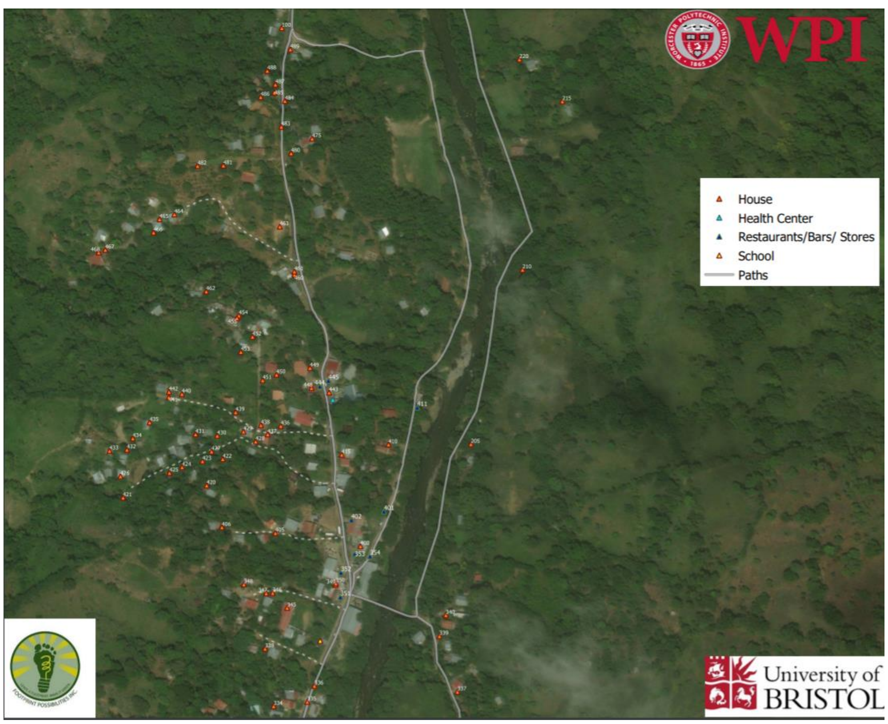
An important aspect of our project was the social infrastructure map. This provides the community a bird's eye view of the local region with a primary focus on the social aspects of the community. This entails the pathways, roads, health services, the school, and the houses themselves. This allowed us to see that most of the population is heavily concentrated around the center of town, which is to be expected, but more importantly that there are almost no houses near the actual water source. Overall, this aspect of our project is not as useful as the survey in terms of findings but gives the community a solid foundation from which to proceed in terms of stabilizing their water system.

The first important thing to note is that the community is divided by the Rio Pecora, and along that division there are no social resources on the east side of the River. Along this same division, there is a division of wealth as the physical condition of the houses appears to be notably worse than those on the west side of the river. As the community expands, it should take advantage of this other side of the river as it has potential to provide the community with new resources. This might provide the poorer section of the community with the ability to improve their current living condition. Our final product does omit some houses as we were not able to survey them, or when we tried to do so, our cellular devices failed to capture our location. Consequently, there appear to be fewer houses on the east side of the river on our map than what is actually present. This is a shortfall that should be remedied by the next project team, or the JAAR.

One of the more interesting aspects of the community is that it only has one school and one health center. We did not have a chance to see the school, so we do not know the quality of it and shall refrain from commenting on it. However, we did get a chance to visit the health center, which is used for all of San Martin, not only San Miguel. The health center was incredibly busy and, according to our project manager Elsie, it is frequently so busy people have to wait outside. This indicates that the community is prone to illness, and the water has a capability to make the residents, especially children, frequently ill. Though the community has a high count of children that get sick from the water, there is most likely an issue with the data (the lack thereof) concerning adults who become sick from the water. Our project manager, Elsie, told us that most adults in the community will often work regardless of whatever health issues they may be facing.

Another important development we provided was a system to give the community addresses. When we arrived in the community, it lacked any sort of address system which made record keeping in the community difficult, and transversal of the community as an outsider an impossibility. What this provides to the community is a way to diagnose problematic areas in the community in regard to the water which may help to isolate the issues within portions of San Miguel. This effectively cuts down on diagnostic time as there is no longer a need to perform an entire sweep of the water system to isolate an issue. Also, it provides an additional piece of information for the JAAR to use when keeping records of its clients.

Figure 4.2.1: Social Infrastructure Map: Center of Town



Provided in Figure 4.2.1 is a portion of the full map of the social infrastructure of the community. This map focuses on the center of town and highlights some of the key aspects talked about above. First, when one looks at the map we see groups of red triangles with corresponding numbers which are the houses within San Miguel. These closely follow the grey lines which unsurprisingly correspond to the roads. Most of the houses are located on the west side of the river along with all of the bars, stores, and the school and the health center. Finally, the dashed lines indicate smaller side roads that only lead to a small number of houses and are dead ends.

Section 4.3: Water Test Results:

Once we completed and evaluated the water tests, we discovered that the water is not safe to consume. We tested the water at six different locations: the beginning of the water system, before the sand filter, before the storage tank, when it leaves the storage tank, a restaurant, and the hostel we were staying at. All the households within the community are supplied with raw water. From our test we found that the water at the source is not safe to drink, and that the sand filter did not accomplish anything in terms of purifying the community's water.

We tested for free chlorine because free chlorine neutralizes the microorganisms in the water. The free chlorine throughout the whole water system had zero parts per million (ppm). Parts per million is like cents out of a hundred, so parts per million (ppm) means the total count of items out of a million. It is standard to use ppm to describe the concentration of some substance in water or soil. One ppm is equivalent to 1 milligram of some substance per liter of water (mg/l) or 1 milligram of some substance per kilogram soil (mg/kg) (Oram, 2004). This is undesirable because any trace of free chlorine indicates that the water has been treated of any dangerous bacteria or organisms in the water (World Health Organization, 2011). Since there is no free chlorine in the water we can conclude that the holding tank is not providing enough chlorine and the water is most likely contaminated by microorganisms that pose a risk to consumers. Throughout the tests, there was no site that had any free chlorine within the water, as seen in tables 4.3.1 and 4.3.2, which tells us that the community is at risk of being exposed to dangerous bacteria and organisms.

The other chemical tested for was total chlorine. Total chlorine is the sum of free chlorine and combined chlorine. Combined chlorine is the chlorine that has already been used to disinfect the organisms. This means that some bacteria has been killed, but it will take up to ten times the amount of free chlorine to sanitize the water (Morris, 2017). The level of total chlorine should always be greater than or equal to the level of free chlorine. If it is more than free chlorine, there are traces of combined chlorine in the water. This means that the water has been treated to some extent (Safe Drinking Water Foundation, 2017). We found the total chlorine was never higher than 1 ppm throughout the whole water infrastructure. This means that there were zero parts of free chlorine in the system, and some traces of combined chlorine. Without an adequate residual amount of free chlorine, the evidence that some bacteria has been treated is a positive attribute, but the amount of chlorine is not enough to fully sanitize the water from dangerous bacteria.

We also tested the pH throughout the water system. The pH scale ranges from zero (acidic), to fourteen (basic). Both extremes can have harmful effects on the body, so a medium reading between six and eight is desirable (Oram, 2003). At the first filters, the water was acidic with a reading less than six. However, when the water leaves the reserve tank the pH rose to between 7.4 and 8.4. This is good because it shows some functionality of the sand filter.

Another aspect of our testing was alkalinity, which refers to the capability of water to neutralize acidity (Peak Alkalinity, 2018). It is important that water has some alkalinity to act as a buffer for the water and make sure it does not get too acidic. The water needs to have between twenty and two hundred ppm to have a stable amount of alkalinity to ensure the water is not acidic. (Peak Alkalinity, 2018). If the alkalinity levels are within the threshold then the water is potable. The water system remained within this threshold, and so this aspect of San Miguel's water system is acceptable.

Our last test was for hardness, because we wanted to see if there were any minerals such as calcium or magnesium present in the water. There are different ranges of hardness for water. It can be slightly hard at 1.0-3.5 grains per gallon (gpg)), moderately hard at 3.5-7.0 gpg, hard at 7.0-10.5 gpg, or very hard water at >10.5 gpg. While hard water is not a health hazard, it can cause scale build up in the pipes, which can lead to bacteria contaminating the water (World Health Organization, 2009). The first test showed the water was slightly hard with ppm of 100 and 120 at two test locations. The second test, after the rain, showed no hardness.

Our data from the free chlorine and total chlorine tests show that the water is not clean enough and may contain harmful microorganism. These organisms can and often do make people ill. The water does have an acceptable pH level, meaning it is not too acidic or too basic. It has a high enough alkalinity to keep the pH level at a proper medium if the water ever gets exposed to acidic substances such as carbon dioxide or organic material within the water. Finally, the water does not contain any minerals, such as magnesium and calcium. We were not able to perform bacterial tests, but this would be the next step for the JAAR in order to completely evaluate the water quality.

Table 4.3.1: Test 1 Results

Test 1	Source	Sand Filter	Before Reservoir	After Res	Casa Llena	La Fonda
Free Chlorine	0	0	0	0	0	0
Total Chlorine	0	.5	.5	1	0	0
pH	<6	<6	<6	7.2	6.8	6.8
Alkalinity	0	0	0	120	0	120
Hardness	0	0	0	100	120	0

Table 4.3.2: Test 2 Results

Test 2	Source	Sand Filter	Before Reservoir	After Reservoir	Casa Llena	La Fonda
Free Chlorine	0	0	0	0	0	0
Total Chlorine	0	0	.5	0	0	0
pH	6.8	8.4	8.4	8.4	7.8	8.4
Alkalinity	80	120	80	100	120	80
Hardness	0	0	0	0	0	0

Section 4.4: Survey Results:

Gaining insight into how the community feels about the water management and the quality of water will give the JAAR the information they need to gain funding for improvements from the local government or other outside parties. The survey results are arguably the most important pieces of information the community will have to make impactful changes. Through analysis we were able to find several conclusions that will help the community progress.

Finding 1: Majority of San Miguel is Drinking from the Tap

In order to accurately measure how the water is affecting the residents of San Miguel, we had to determine how many people were drinking the tap water. We asked residents if they drink tap water, bottled water, rain water, or other. Figure 4.4.1 shows the percentage of people that drink from the tap (grifo) and the percentage who purchase bottled water (embotellada). Eighty-six percent of residents said they drink from the tap, while no residents indicated they were drinking rain water. Every resident who said they drink tap water, also said the use tap water for all other tasks, such as cooking and cleaning. As San Miguel is a low-income community, very few people spend money on bottled water which correlates with Figure 4.4.1 showing only 13% of residents drink bottled water.

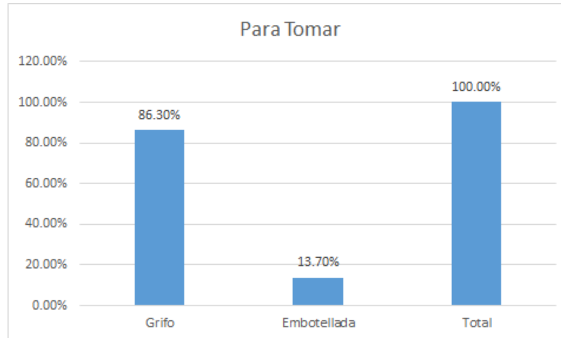


Figure 4.4.1: Drinking water results

Finding 2: Lack of Water Treatment in San Miguel

We included a question in our survey that asked members of the community if they treat their water. This was an important question as there is a sand filter, and a chlorine filter at the top of the mountain, but once the water enters the pipes, it does not get treated again. Figure 4.4.2 shows how many people filter their water in their homes. Fifty-nine percent of residents surveyed said they do not treat their water. The next highest percentage, were people who claimed they treat their water with chlorine at 18%. There is an uncertainty to this percentage as the language barrier may have interfered with the understanding between the two parties.

Chlorine is added to the storage tank at the beginning of the water system and when residents were asked if they treat their water, they could have said they use chlorine, meaning the towns chlorine, not chlorine in their own homes. The next highest percentage is that 16% of community members said they boil their water. Since this is an inexpensive method of cleaning water, we expected more people to boil water, however it is also time consuming which may have contributed to the relatively small portion of the community using this method. Only 6% of the community filters their water, which was expected as it is expensive to buy filters, and they frequently have to be maintained or replaced which adds a constant cost to the already expensive filter.

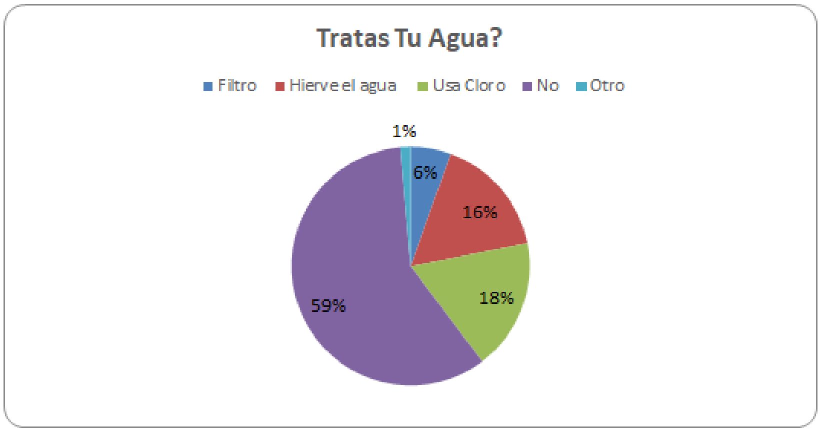


Figure 4.4.2: Water Treatment Results

Finding 3: Water related Illness

One of the most impactful questions we asked was if the community members ever become ill from the water. Thirty percent of the residents we surveyed said they had experienced illness due to water as seen in figure 4.4.3. Although 30% is already a significant number of people, we predict there are more that have not been included. One possible reason for this is that we surveyed by home, not by each individual person. The residents who were responding to these surveys were adults and have been drinking the water for years leading to an immunity to water related illnesses. A second limitation we faced when asking this question was that residents were reluctant to believe that the water in their community could be harmful, leading them to deny being sick as a result of the water.

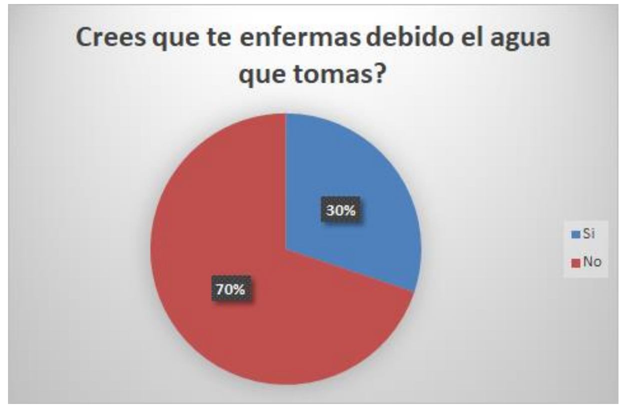
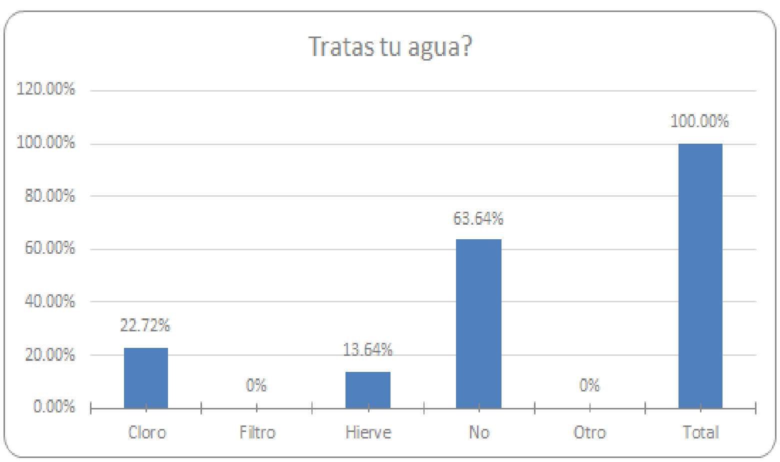


Figure 4.4.3: Water related illness results

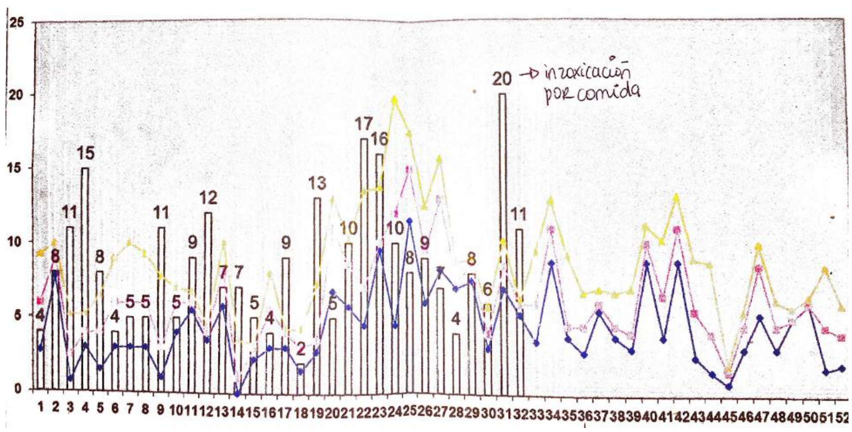
Figure 4.4.4 shows the breakdown of people who treat their water who also responded "Yes" to getting sick from the water. Few people said the boil their water at only 13% and no one said they filter their water. Whereas, 23% of people said they use chlorine, but we suspect that they are either not using the correct amount or are referring to the chlorine at the storage tank, since they are stating that they are getting sick from the water. The majority of residents, however, are not treating their water at all.

Figure 4.4.4: Illness & Water Treatment results



Our next stop was to talk to the local health center. Here, we received a graph as seen in figure 4.4.5 where the x axis is the number of weeks in the year, and the y axis is the amount of illnesses. This graph shows that there were ninety-one children under the age of five that have experienced stomach sickness in the year of 2018 that can be attributed to the water. There are only one hundred and thirty-seven children in San Miguel, so this means that approximately 67% of children have experienced water related illness this year alone.

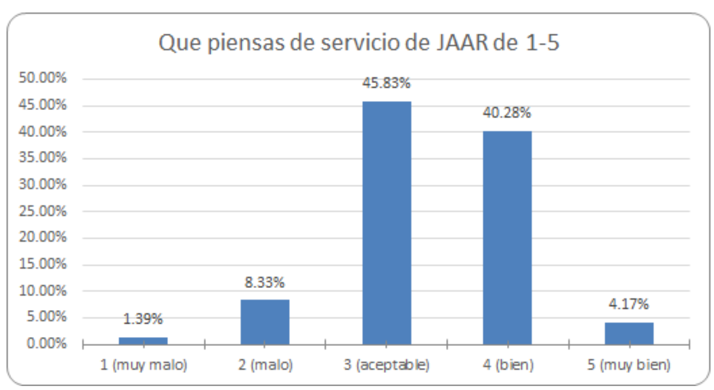
Figure 4.4.5: Water related illness in children



Finding 4: Residents feelings towards the JAAR

The residents of San Miguel and the JAAR need to work together to create the best water system possible. In order to understand how the residents of community felt, we asked people to rate the JAAR on a scale of one to five with one being the worst and five being the best. The results are shown in figure 4.4.6. The highest percentage of people rated the JAAR a three, being average, followed by a four which indicates above average. We did have a JAAR member with us when

Figure 4.4.6: JAAR Results



we were going to houses, so people may have been hesitant to give the JAAR a low rating. We estimate the amount of twos and threes would be higher if we were completing the surveys alone. Additionally, we predict that the question may not be clear, and people reported a four because they were content with the fact they were receiving water, but not necessarily with the quality of water they were receiving. The final limitation that could have affected the responses were that we completed this survey during the rainy season when water levels are high. In the dry season, residents are more frequently without water, so it is likely the responses would be different if the survey was completed during this time.

Finding 5: Money spent on water

We asked residents how much money they spend on water per month. Almost everyone who had an account with the JAAR said that they spent two dollars per month, which is the standard monthly fee. There were responses with more than two dollars suggesting that those residents contribute to the 13% that spend money on bottled water as well. People that did not have accounts with the JAAR generally responded that they spent between zero and three dollars as seen in appendix M. Ninety-seven people in San Miguel are not connected to the JAAR and need to find their own water source, which is likely where this aforementioned money is being spent. There were a few outliers who said they have an account with the JAAR, but only spend one dollar a month on water. These outliers may signify people who are not paying enough to the JAAR and are behind on their payments.

5.0 Recommendations

From our results and findings, we have developed recommendations for the community to improve the water system. We have concluded that the main problems stemmed from the original implementation of the piping system and the lack of organization from the JAAR. Our recommendations aim to improve the quality of water and the communication between the residents of San Miguel and the members of the JAAR.

1. Improved Conditions of the Sand Filter

As previously stated the sand filter is an open tank that uses sand to prevent debris from passing through the water system, which is currently not sealed. The community should install a proper grade of sand in the tank instead of what is currently being used. With proper maintenance the tank can reduce the bacterial population by 90-99% and 44-47% reduction in diarrheal related diseases (Safe Water Systems, 2014). Having an open container allows for debris such as leaves, insects, and small animals to come in contact with the water, which are all possible contaminants that threaten the potability of the water. This sand filter is located incredibly early in the water system and is the main method to clean the water. As discussed above, our test results showed improved water after the sand filter, but if this filter was closed, there would be no risk of contamination, which would allow for improved water quality throughout the water system. We recommend the community find a way to close this filter to improve the quality of water traveling through the pipes and minimize the risk posed to the community.

2. Fix the Pipes

The ideal solution would be to replace the pipes in the entire community since they are fifteen years old. However, this is not a feasible option as it would be expensive to fund and San Miguel most likely does not have the savings to accomplish this in a reasonable time frame. Instead, the damaged pipes should be replaced with new sections of piping.

There is a point in the water system where the pipes are the same diameter, but different thicknesses. It is recommended to have a thicker pipe, which would be sturdier, resist damage, and handle a higher water pressure, therefore lasting longer. This is ideal for industrial application, such as laying a water system down for a community (IMS, 2017) . We recommend that any pipes that need to be replaced are replaced with the thicker pipe in order to improve the quality. An obvious limitation to this recommendation would be the cost, but the higher quality pipe will last much longer. So, when replacing the piping, the JAAR needs to decide if this pipe is worth the money, and if they have the current funds available.

There are many pipes that are connected to trees and hung across rivers and streets. This construction is concerning because these points are very susceptible to cracks and damage as the trees grow, or in the event of a storm. The repair that these events would entail would cost unnecessary time and money. We recommend that these pipes be moved underground below streets to decrease the probability of damage.

3. Increase Pipe Diameter

The water system starts with pipes of three-inch diameter, then decreases to two inches, and at the center of town and for the rest of the community it is one and a half inches. The distribution pipes are only half-inch pipes. We recommend increasing the diameter of the pipes, so residents have more access to water as one-inch piping is normally used to supply a sink or a dishwasher and two-inch piping is normally used to supply a large family household (David Blakin, 2017). The issue with smaller piping for the water system is that it decreases the amount of water that flows through the community causing the pressure to decrease over long distances. A half-inch pipe is very small and slows the movement of water throughout the community. The community may have difficulties addressing this issue as it would require replacing the entire network of pipes.

There are many leaks at the beginning of the water system which provides the best place to start to increase the diameter of the pipes as they already need to be replaced. The maintenance can start at the top and potentially increase the pipes throughout the town over time. Another approach, which could happen at the same time, provided there was funding, would be to start increasing the diameter of the distribution pipes to one inch. This would allow for more water to flow to each house. Although, this is one of the primary issues of the water infrastructure system, but it is most likely one of the most difficult to address.

4. Create a Second Storage Tank

We have been told by members of the community that during the dry season people are without water for days at a time, yet during the rainy season the storage tank is overflowing due to the high-water levels of the Rio Pacora. If the community can build a second water tank, then they would have a larger reserve for the dry season and less water would go to waste. The Rio Pacora has never dried up, but there are time periods when the source is no longer flowing as fast as it does during the rainy season and so water system cannot keep up with the demand of the community leaving houses without water. A second storage tank could be expensive, and the community might not be able to get enough funds to pursue this option. If the JAAR cannot get the funds from the local government, they can look into saving a percentage of the monthly dues the residents pay. This process would take a significant amount of time before the community had sufficient funds, but it is a better option than continuously running out of water during the dry season.

5. Use the Filters That Are Assembled

Next to the sand filter there are four filters that were built, but they were never used or attached to the water system. These are pressurized slow sand filters that require power to function. The town had solar panels to provide power to the filters, but they were stolen leaving the filters unused. When the filters were first built, there were no power lines at this point of the town, but, as the JAAR has informed us, power lines were recently constructed allowing for a new way to power the pressurized slow sand filters. We recommend that the town use these four sand filters by purchasing more solar panels or connecting the power lines to the filters depending on what will be more efficient and cost effective. However, we have a lack of information on these filters and do not know if they would be able to keep up with the town's water supply. Also, we were not able to perform any water tests, so we do not have information on how effective the tanks are at making the water potable. This is field research that needs to be completed before any proper decisions are made. The advantages of having these filters are that they are sealed containers, they have a specialized gradient of sand in them, and they need less frequent maintenance work. The specialized gradient of sand in the tanks will filter the water better than the sand filter in the current tank. In order to maintain the four tanks, the maintenance workers would need to shut off the pumps, turn a lever to force the water out a different hose, then turn on the backwash lever that forces the water through the filter to drain out all the raw material in the filter. Then the workers would turn the backwash lever off, and turn the pumps back on (Pahlen, 2018). Comparably, this is easier and more sanitary than how the workers clean the current sand filter.

6. Improve Organization Within the JAAR

The JAAR should improve their organization and management. Currently, there is no system in place to keep track of which households have paid for water, and which have not. The JAAR needs to develop a standardized approach in which committee members are trained. There needs to be a document containing which households have paid and have not for each month. Along with this, there should be information about the exact amount of money available, how much money is being spent and where the money is being spent. Information on what maintenance work needs to be done should also be included.

We are unsure if the committee members have access to computers, but if they do the committee members could utilize a computer for record keeping. The JAAR could have a basic spreadsheet file with the records of those who have paid this month and those who have not. If there is no access to a computer, the same effect can be achieved with a journal. Either way, the focus is on the fact that the JAAR needs a way to record the history of payments within the community.

7. Communication with the Community

Since San Miguel is a small community most of the residents know the JAAR members as residents, but they do not necessarily know them as committee members. The JAAR should set up a meeting location once a month where the members will be available to discuss concerns about the water system with other community members. This is a realistic possibility for the

JAAR as it is a low time commitment that could produce great results allowing everyone to be on the same page in terms of what people need and what they are not receiving. Most communities that meet on a consistent basis are collectively closer because they are able to openly talk about the issues they are dealing with, and it bridges the knowledge gap about the water system between the households and the JAAR.

6.0 Conclusion

Due to the health effects and current condition of the water infrastructure it is of utmost importance that the JAAR make improvements to the water system in San Miguel. The water system does not have the capability to provide residents with an adequate supply of potable water. The infrastructure is in dire need of support because it will soon be unable to keep up with the demand of the community as the community will only continue to grow in population size as time goes on. By performing surveys, water tests, and mapping the infrastructure, we were able to pinpoint problems and create recommendations for how the community can advance the current system.

The most immediate concerns we discovered were the lack of history on the system, the lack of filters, damaged pipes, and water related illnesses. First, there is no map of the piping system or any information about when it was implemented. The only information we have on the history of the piping system is hearsay which says it was constructed fifteen years ago. The pipes have many cracks that reduce the water pressure, and these cracks allow contamination within the pipes. Combining the cracks with the lack of proper filters, people are getting sick from the water, most notably children under five. This is detrimental to the community as children have weaker immune systems and illnesses can be more dangerous for children than for adults.

We established recommendations that need to be applied if the community wants an improved water system. The necessary improvements are substantial and will require a significant amount of effort, but they are not impossible. The community needs to utilize the four pressurized slow sand filters in order to improve the quality of water before it enters the pipes. The overall piping system in the community was installed improperly. The cracks and leaks are too common in the system and need to be replaced as immediately as possible. A way to prevent future cracks and damage is to use a thicker pipe with the same diameter. We recommend an additional larger storage tank because the current tank cannot hold enough water during the rainy season to survive droughts in the dry season. In order to improve the system, the JAAR needs all the residents connected to the water system to pay the monthly fee, but currently there is no method in place to track who is and is not paying. The JAAR needs implement a method to keep track of this, so they have the proper amount of funds.

6.1 Challenges

Soon after we started our data collection, we ran into some challenges that eventually slowed the progress of the project. When we started doing census work the first week we arrived, we were able to complete a substantial portion of our task. The next day we planned to do more census work and survey as many homes as possible. However, we needed to change some of the questions on the survey to make it clearer as to what we were asking the community members. The issue was that after we updated our survey, the original responses appeared to be missing from the list of the completed surveys. We suspect that the original survey responses were deleted after the survey was updated. Another complication we encountered was when we attempted to regain all of our lost data. It was unsuccessful due to the lack of Internet connectivity in the area. The GPS we were given was often incorrect with the reading it gave us, and this made it quite difficult to complete the task we gave ourselves because we were unable to accurately estimate how far we needed to go to start surveying houses again.

The most difficult challenge to overcome was the language barrier. We did not have a translator accompanying us so when we had to complete surveys and acquire information from the JAAR it was incredibly troublesome. Reflecting on this, if we were to attempt this project again we would have reached out to the community, Footprint Possibilities, or Elsie, our project manager, to try and find a full time translator that could accompany us throughout our time in San Miguel.

6.2 Reflections

Although we are satisfied with the way our project ended, there are some aspects we would have done differently. We would have reached out to WPI to ask for funding for an improved mapping software. We did not know that mWater would not have the features necessary to complete the map the way we had originally planned. Using mWater was a last minute decision as it had all the features our sponsor wanted, leaving us little time to understand all the functions or find what the software lacked. Having funding for a more advanced mapping software would have improved the quality of our maps, and decreased the time spent learning how to operate QGIS. We had a very limited timeframe and we did not know our project would demand the amount of mapping that it did. We would recommend to future teams that they discuss this with the university, as it will only enhance and facilitate the project. In addition to the physical mapping tools, we would have wanted more communication with the community. When we were completing surveys it seemed that people did not know why we were there. This is not an aspect of our project that is under our control, but it is something we could recommend in the future. Despite our challenges, we were able to gather the necessary information to allow the community to move forward and develop a sustainable water system.

References

Anthony M. Pagano, Miles K. Light, Onésimo V. Sánchez, Ricardo Ungo & Eddie Tapiero (2012) Impact of the Panama Canal expansion on the Panamanian economy, Maritime Policy & Management, 39:7, 705-722. Retrieved from https://www-tandfonline-com.ezproxy.wpi.edu/doi/full/10.1080/03088839.2012.729273

Balkin, D. (2017, January 22). Calculating the required water supply line size. Retrieved from http://www.balkanplumbing.com/required-main-water-supply-line-size/

Barnes, R., & Ashbolt, N. (2014, December 8). Development of a Planning Framework for Sustainable Rural Water Supply and Sanitation. *International Studies of Management and Organization, 40 (3).* Retrieved from https://www.tandfonline.com/doi/abs/10.2753/IMO0020-8825400305

Batista-Andrade, J. A., Caldas, S. S., Arias, J. L., Castro, I. B., Fillmann, G., & Primel, E. G. (2016). Antifouling booster biocides in coastal waters of Panama: First appraisal in one of the busiest shipping zones. *Marine Pollution Bulletin, 112*(1-2), 415-419. doi:10.1016/j.marpolbul.2016.07.045 https://ac.els-cdn.com/S0025326X16306233/1-s2.0-S0025326X16306233-main.pdf?_tid=bca6475b-ad3f-45d1-aa77-4e879424ad17&acdnat=1522785223_eccdfd1d9ec71c0381f14cbcf236b83e

Cerrutti, M., & Bertoncello, R. (2003) *Urbanization and Internal Migration Patterns in Latin America*. http://210.74.184.3:8080/international/case/case/1139.pdf

Clasberkeley. (2014). Opportunities for Improving Panama's Potable Water. Retrieved April 03, 2018, from https://clasberkeley.wordpress.com/2014/03/20/opportunities-for-improving-panamas-potable-water/

Clemmens, A. J., & Dedrick, A. R. (1984). Irrigation Water Delivery Performance. *Journal of Irrigation and Drainage Engineering, 110*(1), 1-13. doi:10.1061/(asce)0733-9437(1984)110:1(1) https://naldc.nal.usda.gov/naldc/download.xhtml?id=54654&content=PDF

Dube, T. (2012). Emerging Issues on the Sustainability of the Community Based Rural Water Resources Management Approach in Zimbabwe: A Case Study of Gwanda District. *International Journal of Development and Sustainability, 1*(3). doi:10.2139/ssrn.2346802

Erickson, J. J., Smith, C. D., Goodridge, A., & Nelson, K. L. (2017). Water quality effects of intermittent water supply in Arraiján, Panama. *Water Research, 114,* 338-350. Retrieved from https://www-sciencedirect-com.ezproxy.wpi.edu/science/article/pii/S0043135417300842

Fernàndez-Ibañez, P., Mcguigan, K. G., & Fatta-Kassinos, D. (2017). Can solar water-treatment really help in the fight against water shortages? *Europhysics News*, *48*(3), 26-30. doi:10.1051/epn/2017304. Retrieved from https://www.europhysicsnews.org/articles/epn/abs/2017/03/epn2017483p26/epn2017483p26.html

Greaney, W. (2015). Water Quality Impaired by Agricultural Runoff in Panama and US. Retrieved April 03, 2018, from http://www.truth-out.org/news/item/31916-water-quality-impaired-by-agricultural-runoff-in-panama-and-us

Iglesias, A., & Garrote, L. (2015). Adaptation strategies for agricultural water management under climate change in Europe. *Agricultural Water Management*, *155*, 113-124. Retrieved from https://ac.els-cdn.com/S037837741500089X/1-s2.0-S037837741500089X-main.pdf?_tid=458b2152-1689-4e21-8a68-66f4372592ea&acdnat=1524009064_eb015adf94dd9ffb676fd1613c76e730

IMS, O. (2017, January 09). Olympus IMS. Retrieved from https://www.olympus-ims.com/en/applications/wall-thickness-of-plastic-pipe/

Jiang, Y. (2015). Chinas water security: Current status, emerging challenges and future prospects. *Environmental Science & Policy, 54*, 106-125. Retrieved from https://ac-els-cdn-com.ezproxy.wpi.edu/S1462901115300095/1-s2.0-S1462901115300095-main.pdf?_tid=8e2dad9e-ff61-42fe-a960-b36d8b14b135&acdnat=1523923038_7d24b45a6feb274e5771e2f964b7f301

Kurokawa M., Ono K., Kimura K., Sakai H., Ueno R., Yanagida J., Imura S., Inoue W., Kaneko E., Yamamoto S., Nomura H., Khadka JB., & Rai SK. (2017). Reduction of Diarrheal Diseases Cases by the Introduction of Sand-Filtered Drinking Water in a Rural Western Hilly Area in Nepal. *Nepal Med Col*, 19 (2), 59-65. Retrieved from http://nmcth.edu/images/gallery/Vol%2019.%20No%202.%20June%202017/Kurokawa_M.pdf

Logsdon, G. S. (2008). *Water filtration practices : including slow sand filters and precoat filtration*. Retrieved from https://ebookcentral-proquest-com.ezproxy.wpi.edu

Mechenich, C., & Andrews, E.(2004). Interpreting Drinking Water Test Results. *Home Water Safety*. Retrieved From https://adams.uwex.edu/files/2013/01/Home-Water-Safety-Interpreting-Drinking-Water-Test-Results.pdf

Microbiologically Induced Corrosion (MIC). (n.d.). Retrieved from https://inspectioneering.com/tag/microbiologically induced corrosion

Nitzsche, K. S., Lan, V. M., Trang, P. T., Viet, P. H., Berg, M., Voegelin, A., . . . Kappler, A. (2015). Arsenic removal from drinking water by a household sand filter in Vietnam — Effect of filter usage practices on arsenic removal efficiency and microbiological water quality. *Science of The Total Environment, 502*, 526-536. doi:10.1016/j.scitotenv.2014.09.055 Retrieved from https://ac.els-cdn.com/S0048969714013771/1-s2.0-S0048969714013771-main.pdf?_tid=1568462f-155a-4782-8da8-817faabcf11c&acdnat=1522895420_ed752e743e139be24b40eb6f53d90ea4

Oram, B. (2014). Water Research Center. Retrieved from https://www.water-research.net/index.php/drinking-water-issues-corrosive-water-lead-copper-aluminum-zinc-and-more

Panama - Poverty and wealth. (n.d.). Retrieved April 09, 2018, from http://www.nationsencyclopedia.com/economies/Americas/Panama-POVERTY-AND-WEALTH.html

Peak Alkalinity | Alkaline Water & Premium Water Ionizers. (n.d.). Retrieved from https://peakalkalinity.com/?gclid=Cj0KCQjw9NbdBRCwARIsAPLsnFZWmddttTPsT6wfjW_2pibW6DzKHSC3YbsvmvH3jAPQkNfPIC-pntkaAh2OEALw_wcB

Pérez, O. J. (2000). *Post-invasion Panama: The challenges of democratization in the New World Order*. Lanham, Md: Lexington Books.

Perlman, H. (2018, August 8). *pH- Water Properties*. Retrieved from https://water.usgs.gov/edu/ph.html

Perlman, H. . (2016, December 15). Water Hardness. Retrieved from https://water.usgs.gov/edu/hardness.html

Prado, L. A. (2015). *Rural Water Sustainability in Latin America and the Caribbean.* Retrieved from https://www.tdx.cat/bitstream/handle/10803/322784/lap1de1.pdf?sequence=1&isAllowed=y

Ramírez-Sánchez, M. I, Doll, S. & Bandala, E. R. (2015). Drinking Water and Sanitation in Central America: Challenges, Perspectives, and Alternative Water Treatment. *Water Challenges and Solutions on a Global Scale* (53-70).

Reservoir Design and Storage Manuel (2001). Retrieved from http://www.webpages.uidaho.edu/ce431/Handouts/WA%20DOH%20Water%20Res%20Guidelines.pdf

Safe Water System. (2014, May 02). Retrieved from https://www.cdc.gov/safewater/sand-filtration.html

Sciotine, J., Ravikumar, R. (1999). Fishery Harbour Manual on the Prevention of Pollution- Bay of Bengal Programme.

Systems, P. (2018). Cleaning the pool filter sand. Retrieved from https://www.pahlen.com/users-guide/cleaning-filter-sand/

Total Chlorine Analysis for Elementary Operation Water Drop. (n.d.). Retrieved from https://www.safewater.org/operation-water-drop-listings/2017/2/4/elementarytotalchlorine

Total water Hardness. (n.d.) *Vernier Software and Technology*. Retrieved from http://www2.vernier.com/sample_labs/WQV-14-COMP-total_water_hardness.pdf

Water Quality Assessment: Chemical. (n.d.). Retrieved from http://www.cotf.edu/ete/modules/waterq3/WQassess3.html

What Are Nitrates? (n.d.). Retrieved from http://www.bfhd.wa.gov/info/nitrate-nitrite.php

World Health Organization (2009) Hardness in Drinking Water http://www.who.int/water_sanitation_health/dwq/chemicals/hardness.pdf

World Health Organization (2011) *Measuring Chlorine Levels in Water Supplies*, http://www.who.int/water_sanitation_health/publications/2011/tn11_chlorine_levels_en.pdf

WorldoMeters (n.d.). Retrieved from http://www.worldometers.info/world-population/panama-population/

Appendix A: Survey Questions

Completo? (Complete)
Si (yes)
No (No)
No ocupado (Not occupied)

Num de niños (Number of children)
< 6 años (Under 6 years)

< 18 años (Under 18 years)

Num de adultos (Num of adults)

Profesion del titular de la casa (Profession of the owner of the house)

¿Ocupacion del titular de la casa? (Occupation of the owner of the house?)
Asalariado (Salaried)
No Asalariado (Not Salaried)
Independiente (Independent)

¿Tienes cuenta de agua con JAAR? (Do you have an account with the JAAR)
Si (Yes)
No (No)

Su cuenta de JAAR esta actualmente activa? (Is your account with the JAAR active?)
Si (Yes)
No (No)
No Aplica (Not applicable)

¿Cuánto pagas al mes por agua? (How much do you pay a month for water?)

¿Cuantos dias a la semana tienes agua? (How many days a week do you have water?)

En los dias que tienes agua ¿Cuantas horas cuenta con el servicio? (On the days you have water, how many hours do you have service?)

¿A que hora del dia usas mas agua, en la mañana, tarde o noche? (When do you use the most water, in the morning, afternoon, or night?)
Mañana (5am- 12pm) (Morning)
Tarde (12pm-5pm) (Afternoon)
Noche (6pm-9pm) (Night)

Para cada uno de los siguientes ¿qué tipo de agua usa? (For each of the following, What type of water do you use?)

Para cocinar: (To cook)
Grifo (Tap)
Embotellada (Bottled)
Otros (especificar) (Other)
Lluvia (Rain)

Para ducharse: (To shower)
Grifo
Embotellada
Otros (especificar)
LLuvia

Para limpiar: (To clean)
Grifo
Embotellada
Otros (especificar)
Lluvia

Para tomar: (To drink)
Grifo
Embotellada
Otros (especificar)
Lluvia

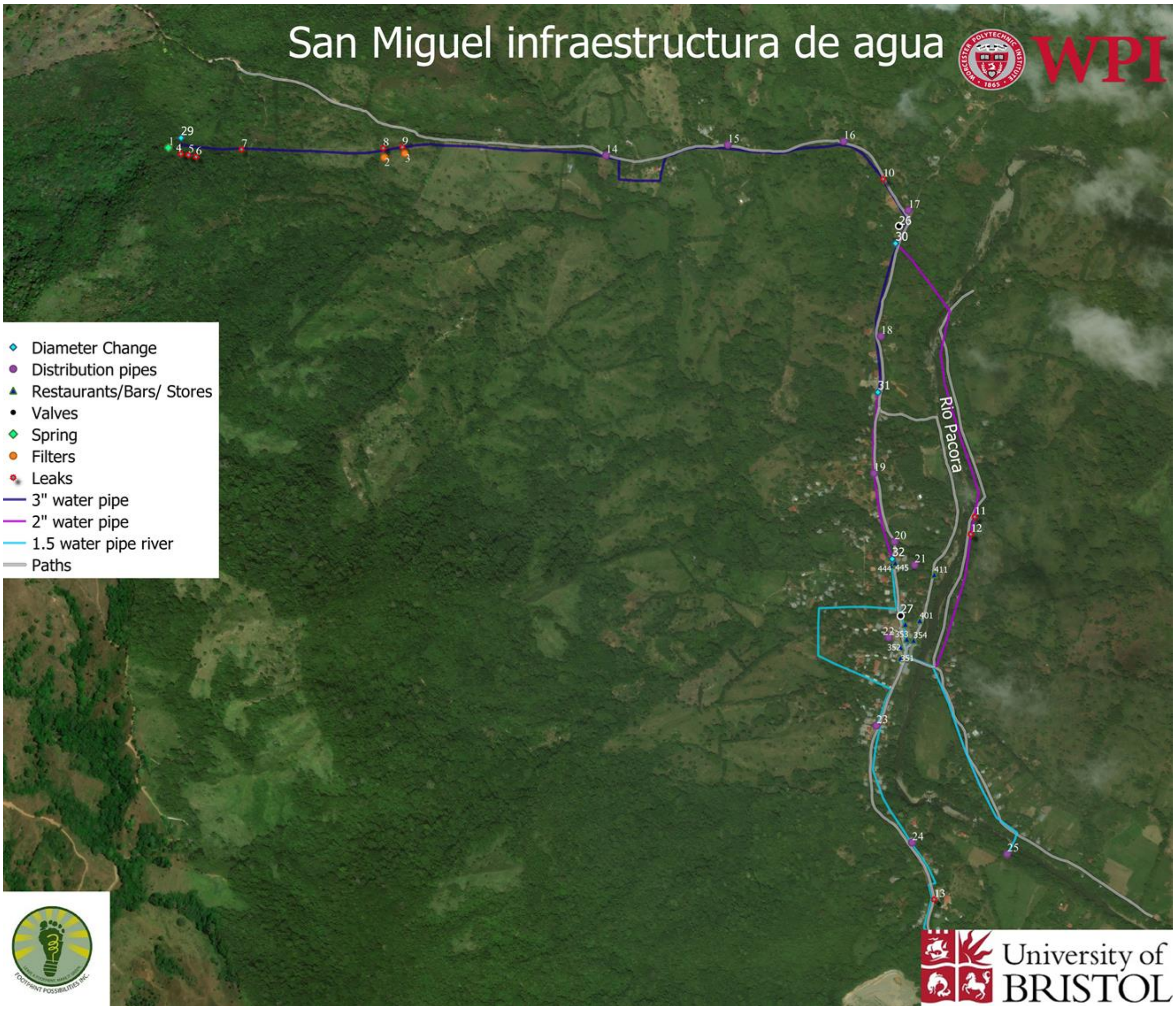
Crees que te enfermas debido el agua que tomas? (Do you think you get sick from the water you drink?)
Si (Yes)
No (No)

¿Tratas tu agua? (Do you treat your water?)
Hierve el agua (Boil the water)
Usa cloro (Use chlorine)

No
Otro (Other)
Filtro (Filter)

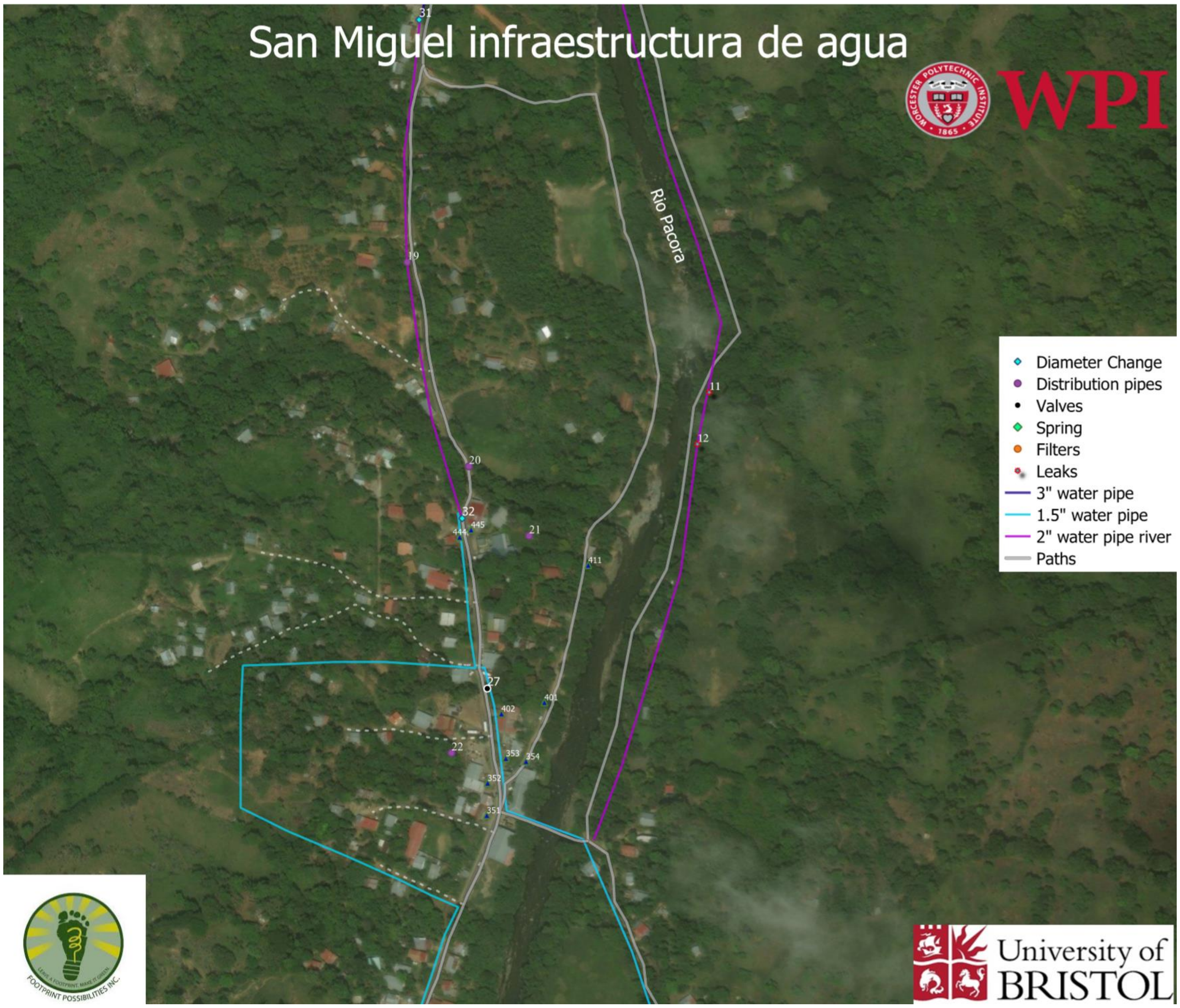
Que piensas de servicio del JAAR de 1-5 (What do you think of the service of the JAAR from 1-5?)
1 muy malo (Very bad)
2 malo (Bad)
3 aceptable (Acceptable)
4 Bien (Good)
5 Muy Bien (Very Good)

Appendix B: Complete Map of Water System in San Miguel

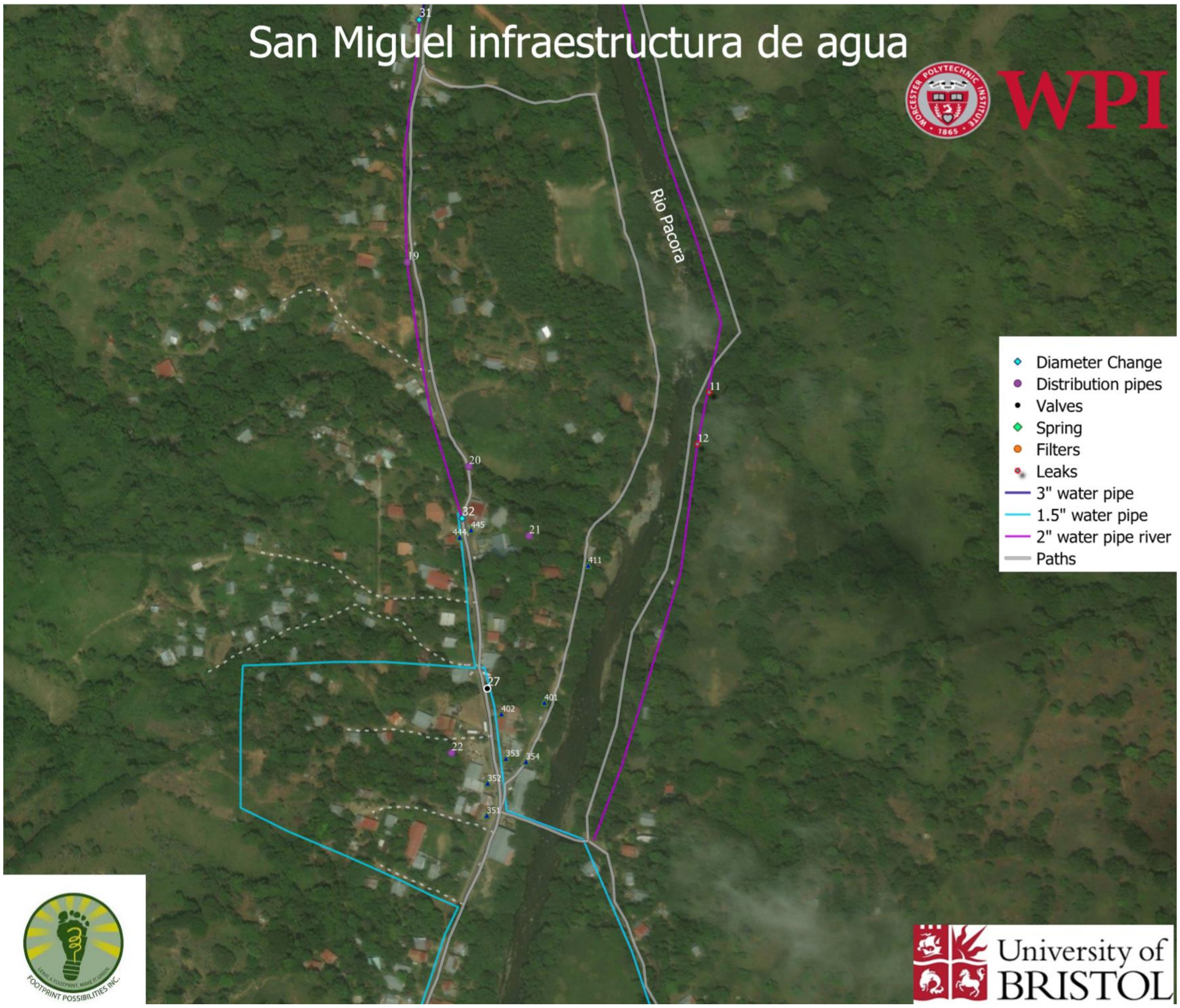


Appendix C: Upper Map of Water System in San Miguel

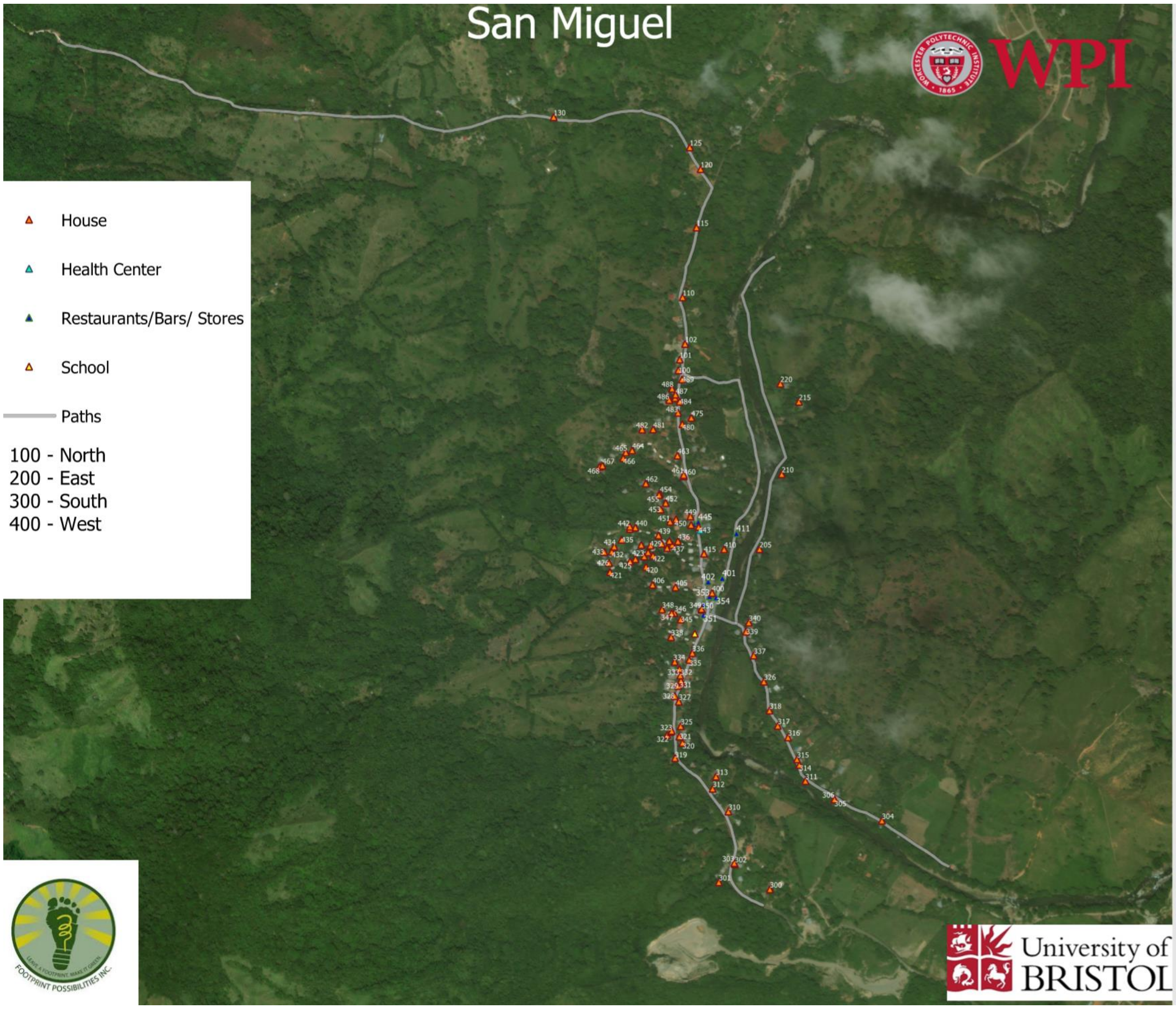
Appendix D: Center Map of Water System in San Miguel



Appendix E: Lower Map of Water System in San Miguel

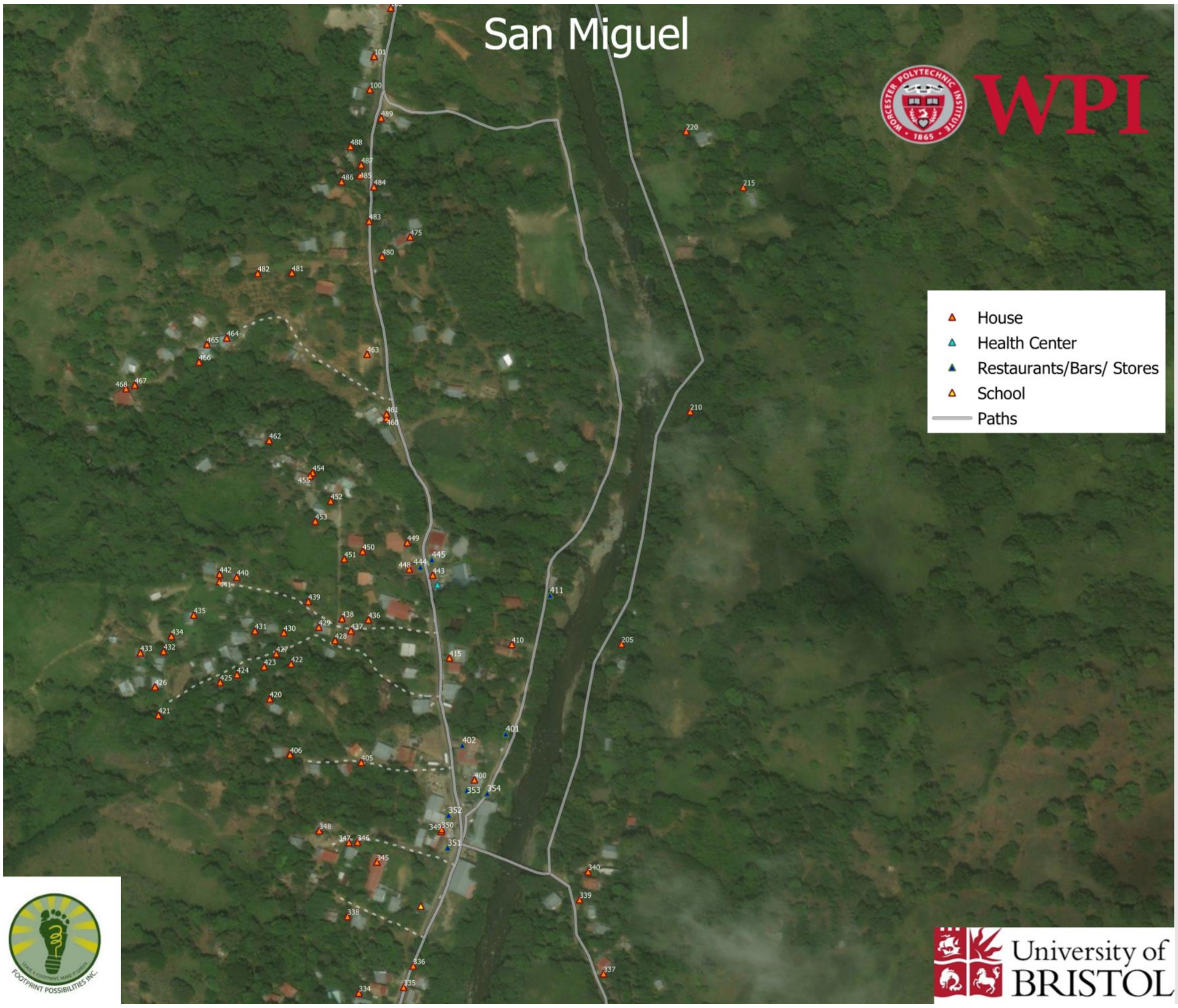


Appendix F: Complete Map of Social Infrastructure of San Miguel



Appendix G: Upper Map of Social Infrastructure in San Miguel

Appendix H: Center Map of Social Infrastructure in San Miguel



Appendix I: Lower Map of Social Infrastructure in San Miguel

Appendix J: House Locations

Complete	Latitude	Longitude	House Number
No	9.21649277	-79.25317138	300
Si	9.21667381	-79.25449588	301
No	9.21713815	-79.25408097	302
No	9.21716392	-79.25409564	303
Si	9.21824947	-79.25026517	304
No	9.218794671	-79.25149765	305
No	9.218794671	-79.25149765	306
No	9.21848434	-79.25424854	310
No	9.219265021	-79.25224934	311
Si	9.21906696	-79.25465693	312
Si	9.21937839	-79.25457033	313
No ocupado	9.21967783	-79.25240759	314
Si	9.219820951	-79.2524692	315
No	9.220395782	-79.25272761	316
No	9.220677372	-79.25296666	317

No	9.221069897	-79.25318149	318
No	9.21985269	-79.25563225	319
No	9.22024244	-79.25543864	320
Si	9.22040523	-79.25552053	321
Si	9.22044325	-79.25583531	322
No	9.22052128	-79.25574191	323
No	9.22054786	-79.25571795	324
Si	9.2206682	-79.25548486	325
No	9.221810438	-79.25332641	326
Si	9.22129856	-79.25553563	327
No	9.22144316	-79.25563386	328
No	9.22169855	-79.25554774	329
Si	9.22178241	-79.25544587	330
No	9.22183673	-79.25547879	331
Si	9.22196804	-79.2554962	332
No	9.22213257	-79.25551771	333
Si	9.22231799	-79.25563873	334
No	9.2223666	-79.2552637	335

No	9.22254196	-79.25518348	336
Si	9.222477931	-79.25359011	337
No	9.22295095	-79.25573388	338
No	9.2230896	-79.2537906	339
No ocupado	9.223320438	-79.25371877	340
No	9.22295095	-79.25573388	345
No	9.223563848	-79.25564954	346
Si	9.223561124	-79.25572171	347
Si	9.223658647	-79.2559704	348
Si	9.223653283	-79.2549494	349
Si	9.223653283	-79.2549494	350
Si	9.224079293	-79.25467079	400
No	9.224224007	-79.25561886	405
Si	9.22428729	-79.2562149	406
Si	9.225197947	-79.254358	410
No	9.225086044	-79.25488025	415
Si	9.224748085	-79.25638413	420
No	9.224613388	-79.25731704	421

Si	9.225037387	-79.25620576	422
Si	9.225014546	-79.25643174	423
No	9.22494791	-79.25665881	424
Si	9.224885548	-79.25679937	425
Si	9.224847662	-79.25734562	426
No	9.225121122	-79.25633065	427
No	9.225230422	-79.25583864	428
Si	9.225340351	-79.25597442	429
Si	9.225294921	-79.25626704	430
No	9.225309924	-79.25650852	431
No	9.22514061	-79.2572732	432
Si	9.225128791	-79.25746799	433
No	9.225265165	-79.25720866	434
Si	9.225440808	-79.25702082	435
No	9.225401916	-79.2555586	436
No	9.225310301	-79.25570495	437
Si	9.22541101	-79.2557803	438
No	9.22555346	-79.2560621	439

No	9.22575383	-79.2566609	440
Si	9.225717913	-79.25680658	441
No	9.225789201	-79.25680264	442
No	9.225769839	-79.25502006	443
Si	9.225819712	-79.2552167	448
Si	9.226039778	-79.25523338	449
Si	9.225966269	-79.25560646	450
No	9.225904369	-79.25576043	451
No	9.226383017	-79.25587434	452
No	9.226216427	-79.25600334	453
Si	9.226617208	-79.25602597	454
Si	9.22658917	-79.25604709	455
Si	9.227066436	-79.25540613	460
No	9.227100802	-79.25540697	461
No	9.226882453	-79.25638916	462
No	9.227595669	-79.25556974	463
Si	9.227729989	-79.2567443	464
Si	9.227676638	-79.2569101	465

Si	9.22753117	-79.25697732	466
No	9.227339937	-79.25751451	467
No	9.227310894	-79.25758836	468
Si	9.228563737	-79.2552089	475
No	9.228402427	-79.25544376	480
No	9.228267814	-79.25619914	481
No	9.228263497	-79.25648572	482
No	9.22869395	-79.2555529	483
Si	9.228977971	-79.2555125	484
No	9.229071052	-79.25563035	485
Si	9.229021389	-79.25578281	486
No	9.22915881	-79.25561903	487
Si	9.229310313	-79.2557093	488
No	9.229545761	-79.25545198	489
Si	9.229780538	-79.25554653	100
Si	9.230055716	-79.25551032	101
No	9.230455114	-79.25537151	102
No	9.231648613	-79.25543572	110

No	9.233436305	-79.25507496	115
No	9.234931679	-79.25496792	120
No	9.235488405	-79.25525014	125
No	9.236261467	-79.2587811	130
Si	9.225201462	-79.25343965	205
Si	9.227120918	-79.2528644	210
Si	9.228973738	-79.25242041	215
No	9.229435371	-79.25289885	220
No			
No			

Appendix K: Restaurant Locations

Number	Latitude, Longitude	Altitude	Accuracy
351	9.223519, -79.254895	100.931	5
352	9.223788, -79.254888	110.612	5
353	9.223994, -79.254734	113.328	10
354	9.223968, -79.254564	109.259	10
401	9.224460, -79.254409	108.116	10
402	9.224366, -79.254772	116.657	5
411	9.225604, -79.254039	115.525	5
444	9.225838, -79.255124	118.385	5
445	9.225899, -79.255028	118.352	5

Appendix L: Water System Locations

Filters

Number	Location	Altitude	Description
1	9.236316, -79.273057	408.988	Spring and grate filter, start of the water source at top of the mountain
2	9.236169, -79.268008	293.766	Second sand filter
3	9.236346, -79.267515	295.311	Holding tank with chlorine filter

Leaks

Number	Location	Altitude	Description
4	9.236152, -79.273030	409.925	leak in pipe
5	9.236135, -79.273011	382	leak in pipe
6	9.236095, -79.272889	380	leak in pipe
7	9.236205, -79.271546	370.429	leak in pipe
8	9.236237, -79.267965	305.143	Leak in pipe at second filter

9	9.236261, -79.267481	293.616	Leak right before holding tank. Stick placed to try and stop leak
10	9.235468, -79.255334	157.466	Leak in pipe
11	9.227044, -79.253018	135	Leak in pipe on other side of the river
12	9.226612, -79.253118	145	Leak in pipe on other side of the river
13	9.217504, -79.254046	154	Leak in pipe

Feeder Connection

Number	**Location**	**Altitude**	**Description**
14	9.236059, -79.262335	228.507	3 houses
15	9.236321, -79.259257	205.797	2 houses
16	9.236410, -79.256330	172.797	6 houses, starts at the top of the decline
17	9.234544, -79.254745	142.692	3 houses
18	9.231547, -79.255388	167.854	6 houses
19	9.228129, -79.255566	158.542	6 houses hanging pipe
20	9.226427, -79.255046	121.331	Unknown amount of houses
21	9.225848, -79.254538	157	Unknown amount of houses

22	9.224039, -79.255193	140	Through a goat pen unknown amount of houses
23	9.221838, -79.255501	127	4 houses
24	9.218921, -79.254603	119	2 houses
25	9.219168, -79.251946	117.588	10 houses

Valve

Number	Location	Altitude	Description
26	9.234544, -79.254745	142.692	Valves on distribution pipe
27	9.224575, -79.254891	133	Pipe crosses the road and has a valve that goes to a few houses

Diameter

Number	Location	Altitude	Description
29	9.236316, -79.273057	408.988	Beginning of pipe 3"
30	9.233860, -79.255020	140.734	Pipe goes across river and changes from 3" to 2"
31	9.230149, -79.255466	151.436	Pipe changes from 3" to 2"

32	9.225993, -79.255103	107	Pipe changes from 2" to 1.5"

Appendix M: Money Spent on Water

Numero de Casa	¿Tienes cuenta de agua con JAAR?	¿Cuánto pagas al mes por agua?
300		
301	No	0
302		
303		
304	Si	2
305		
306		
310		
311		
312	No	6
313	Si	8
314		
315	No	2
316		
317		
318		

319		
320		
321	Si	2
322	No	2
323		
324		
325	No	5
326		
327		
328	Si	24
329		
330		
331	Si	2
332		
333	Si	2
334		
335	Si	2
336		

337		
338	Si	2
339		
340		
345		
346		
347	Si	2
348	No	2
349	Si	2
350	Si	2
400	Si	2
405		
406	Si	2
410	No	2
415		
420	No	0
421		
422	No	1

423	No	0
424		
425	No	1
426	No	2
427		
428		
429	No	1
430	No	0
431		
432		
433	No	2
434		
435	No	0
436		
437		
438	Si	14
439		
440		

441	No	1
442		
443		
448	Si	2
449	Si	2
450		
451		
452		
453		
454	Si	2
455	Si	2
460	Si	
461		
462		
463		
464	Si	2
465	Si	1
466	Si	2

467		
468		
475	No	
480		
481		
482		
483		
484	No	1
485		
486	No	1
487		
488	No	1
489		
100	No	1
101	Si	2
102		
110		
115		

120		
125		
130		
205		2
210	No	2
215	No	2
220		